A study of hearing damage caused by personal MP3 players

Adriano Farina

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Objectives

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- Following international and european standards about measurements techniques
- Using a test signal that is both standard and similar to real-life music

The “IEC” test signal

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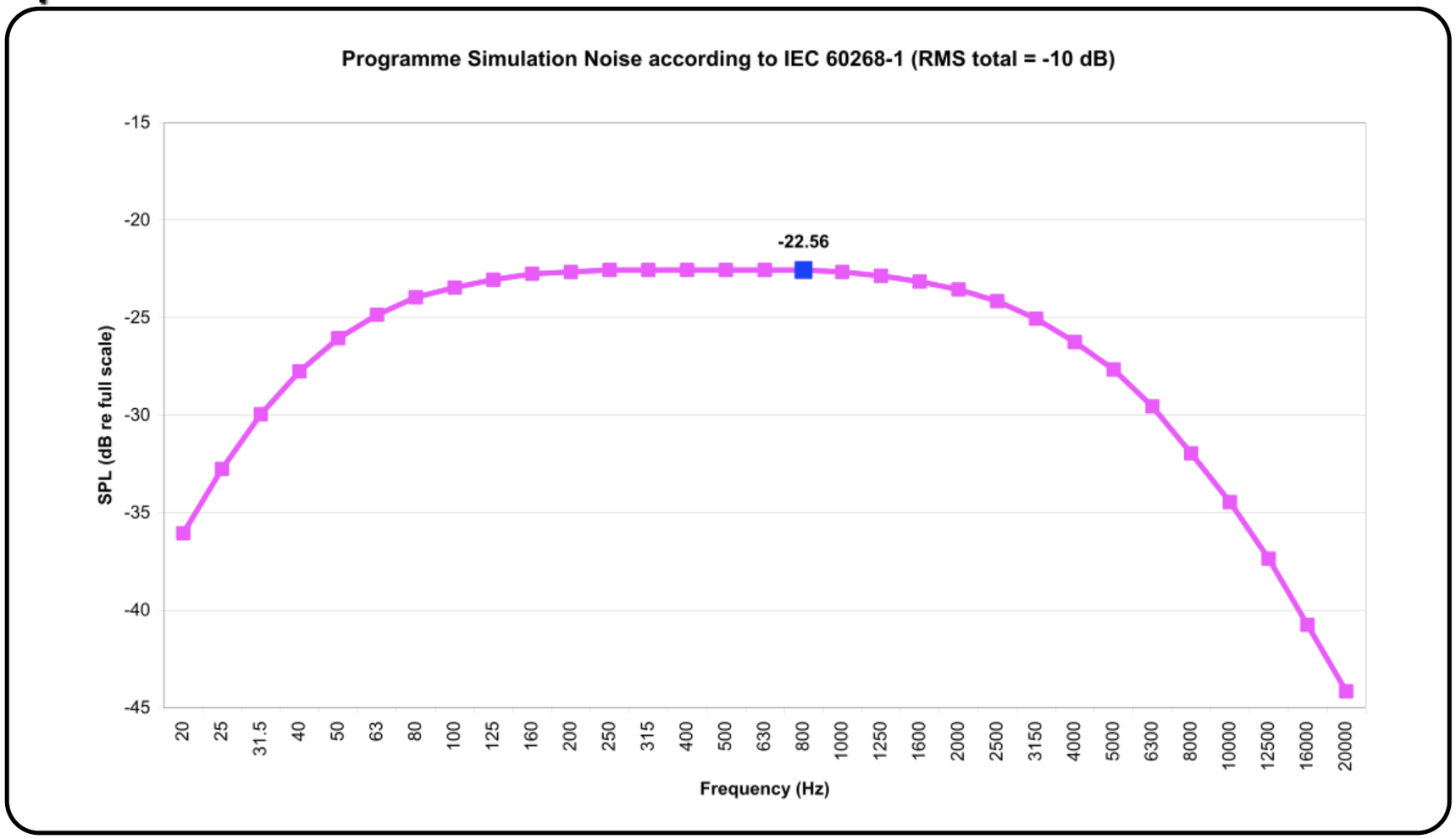

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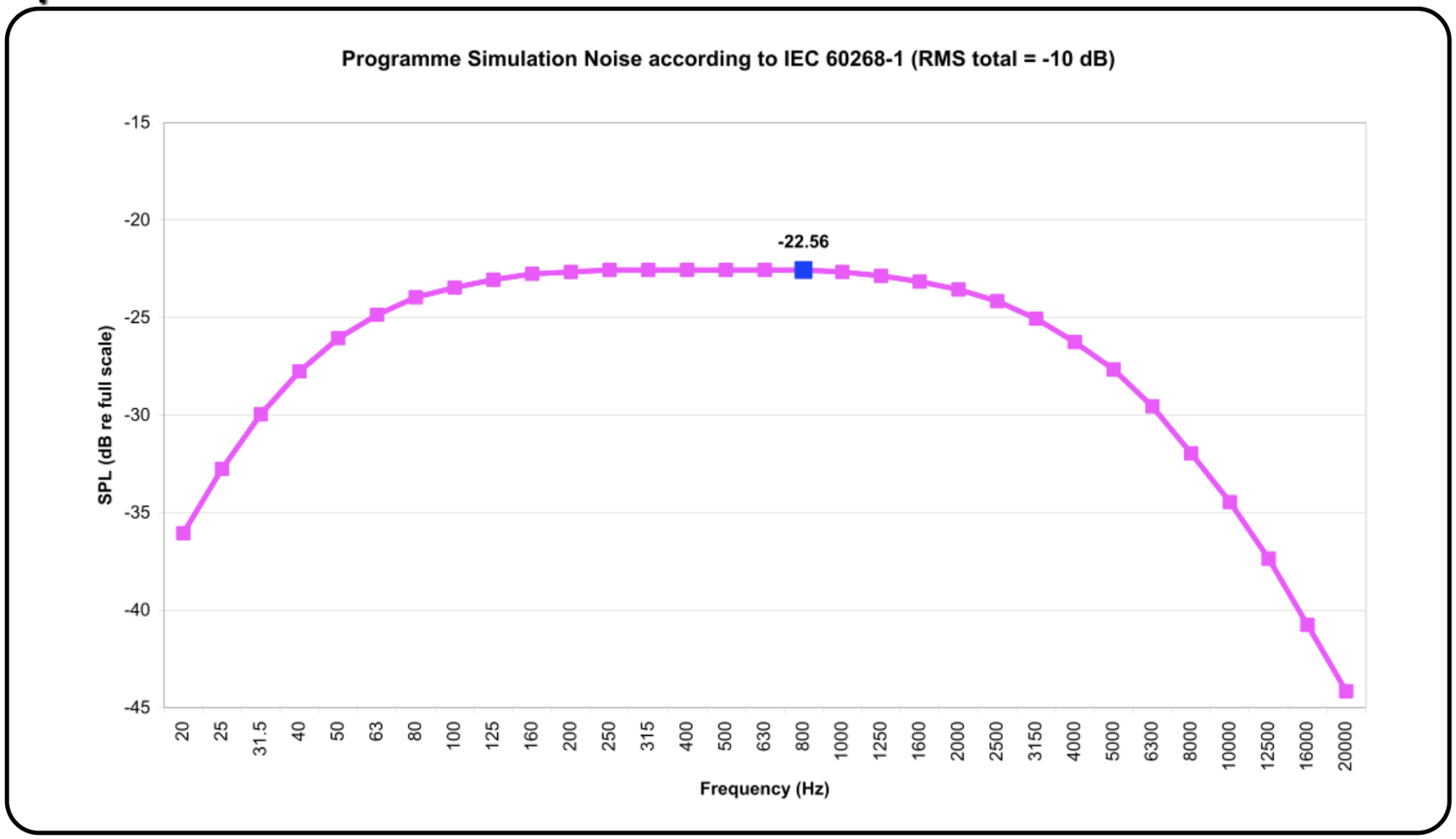

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3. The resulting sound had an average RMS value of -16dBFS instead of the standard -10

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6. The resulting sound was measured compliant with the IEC standard

7. However, it was noted by Alastair Hardie, a Senior Electronic Engineer for Frontier Silicon, that the Crest Factor had a 3.1373 / 3.1372 ratio, instead of the 1.8/2.2 specified in section 5.1 of standard EN 50332-1:200

Crest Factor Problem

Crest Factor Problem

- While the IEC standard states that the programme simulation noise must have a crest factor ranging between 1.8 and 2.2, it was technically impossible to generate such a noise. In fact the standard is written considering an analog crest factor measurement.

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- Specifying a window width of 35 ms, this tool computes correctly the pseudo-peak value as maximum RMS, if you add 3dB to the result (or by specifying that 0 dB = FS sine wave). It was checked that with these settings one gets the readings specified in table A-II of the IEC standard, employing a 5kHz tone burst of 1ms length.

- After calibrating such a quasi-peak digital detector, I analyzed again my WAV file, and the result found was that the maximum peak value detected is roughly -4.58 dB FS. Hence, the peak-to-RMS ratio is 5.42 dB, which means a ratio equal to 1.87, which is inside the range dictated by the EN standard

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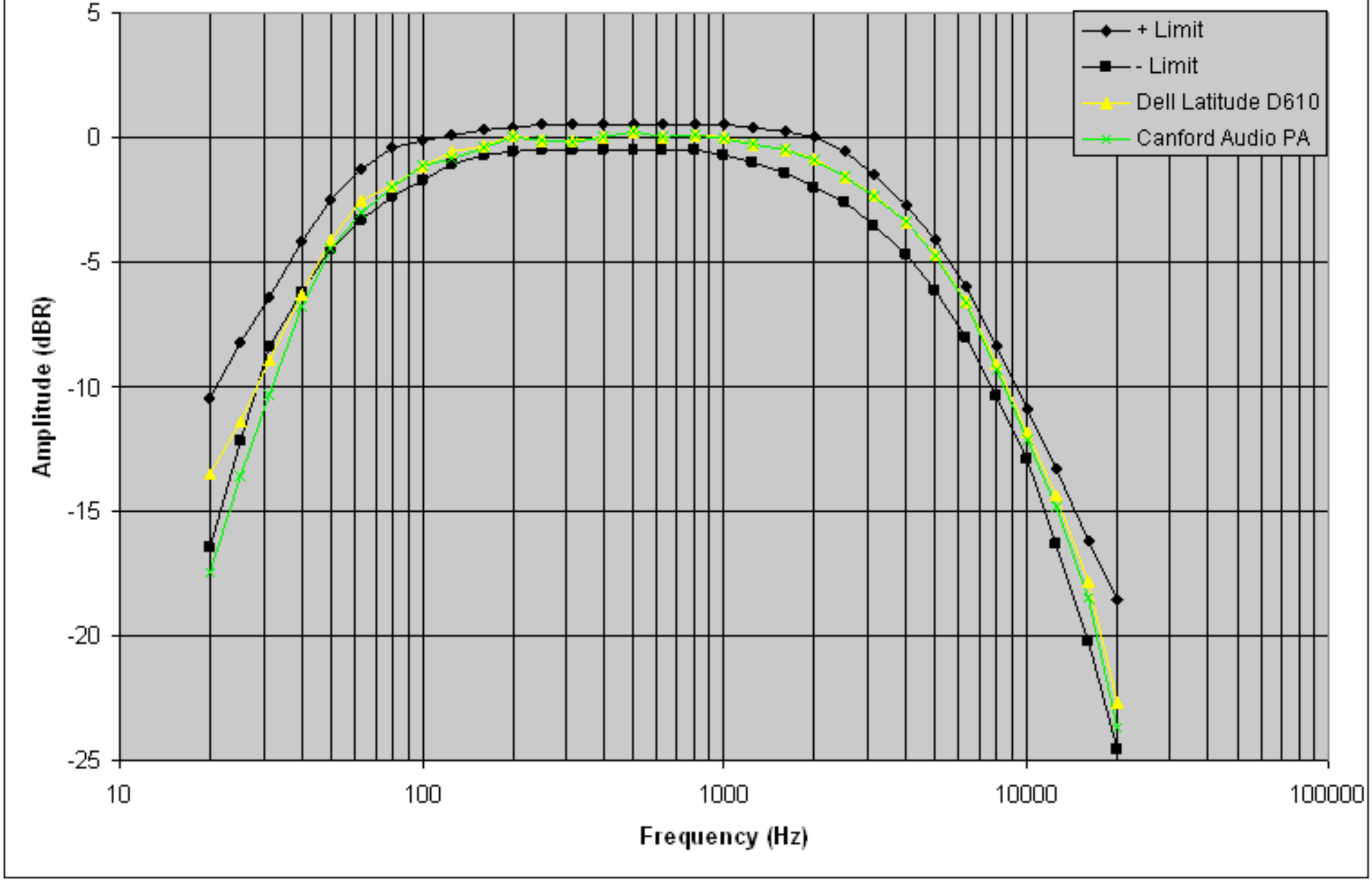
- Furthermore Mister Hardie had the signal tested both by the National Physical Laboratory of London and by another independent lab, and was found standard-compliant (not considering a 0.09 dB error to be relevant).

IEC 60268-1 Signal Characteristics



Since the “IEC” test signal is made to measure the maximum SPL possible for a device, we also used a signal representative of music

The “Music” test signal

The “Music” test signal

The second test signal employed was the “Music” signal, which was based on the average 1/3 of octave spectrum of all the music pieces stored on the measured DAPs (more than 30 GB)

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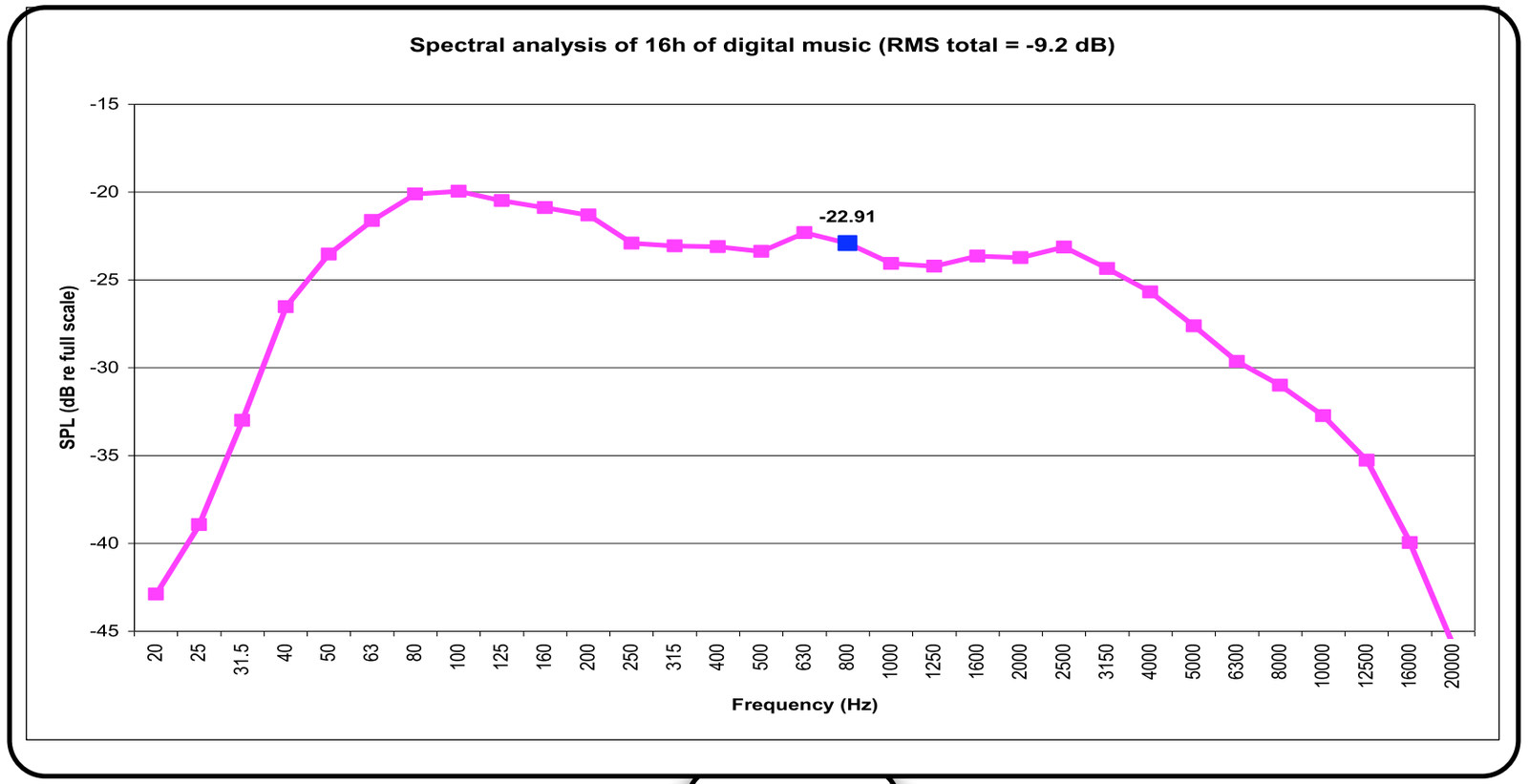

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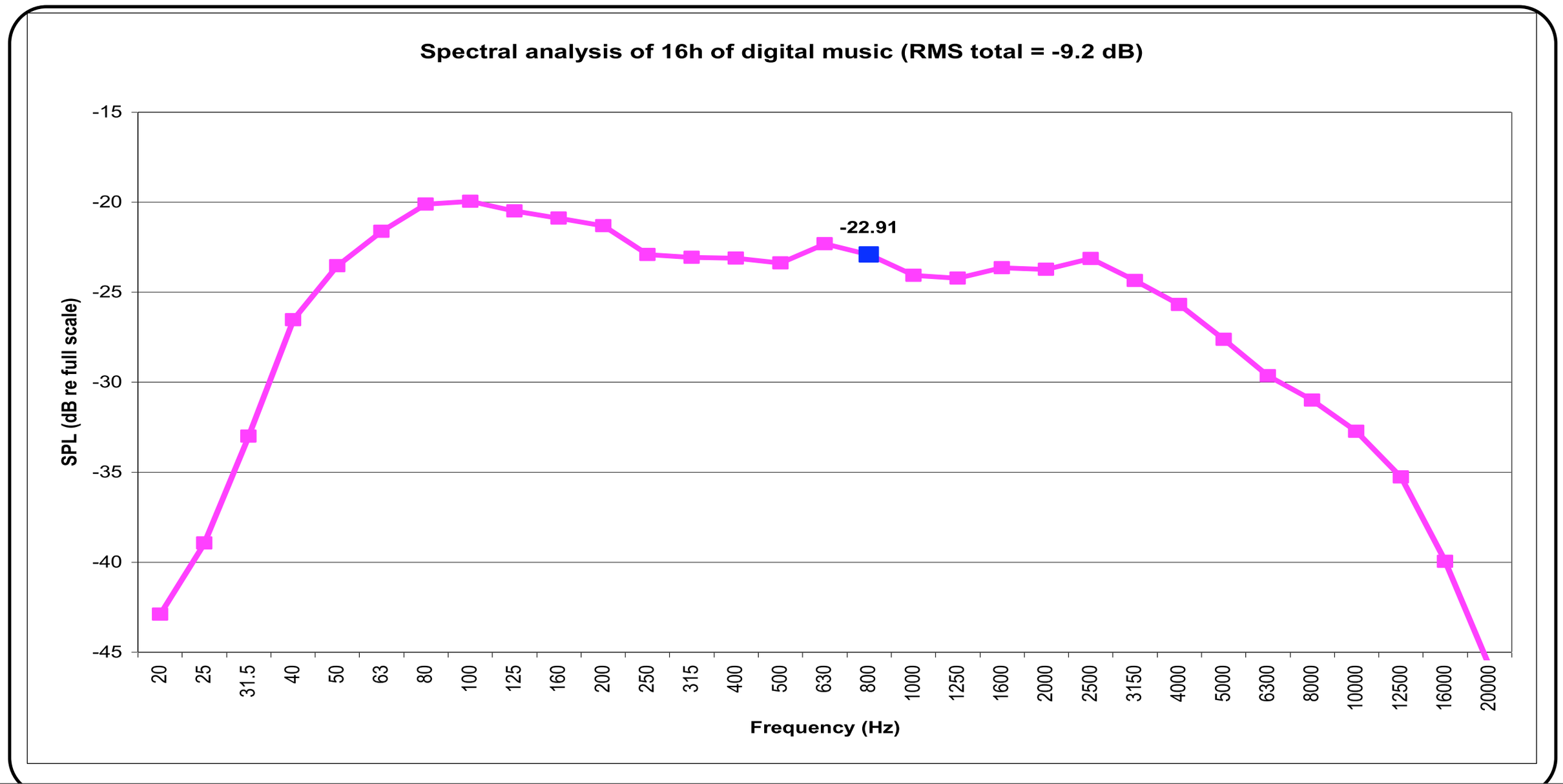

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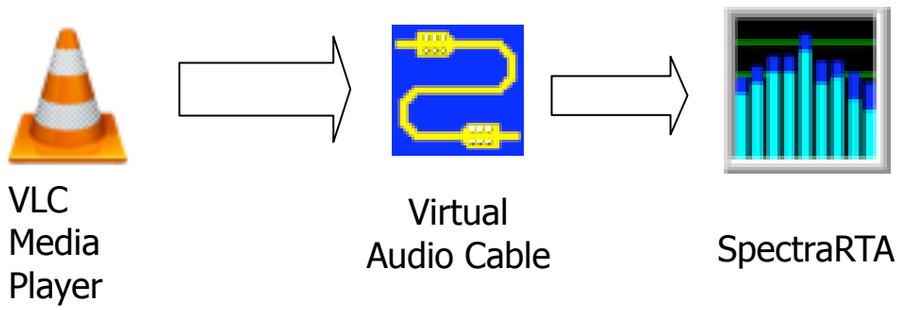

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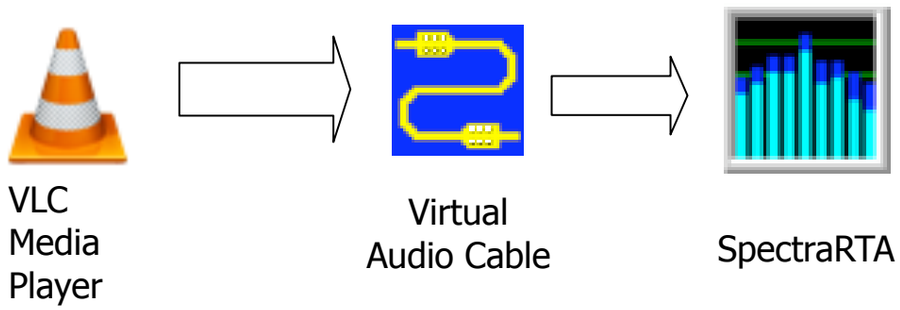

Plays the collected music

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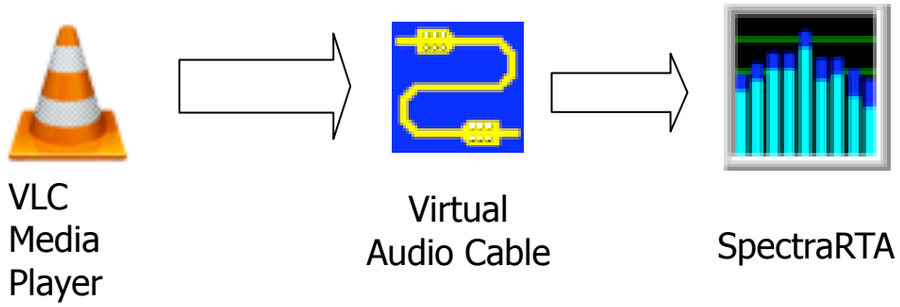

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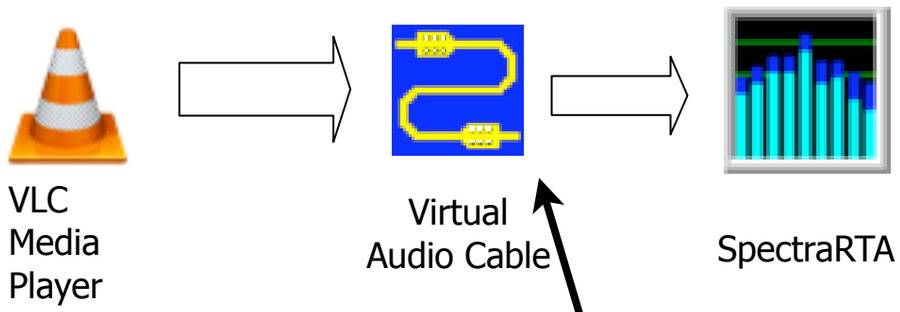

Digitally reroutes audio output to input

Generating the signal

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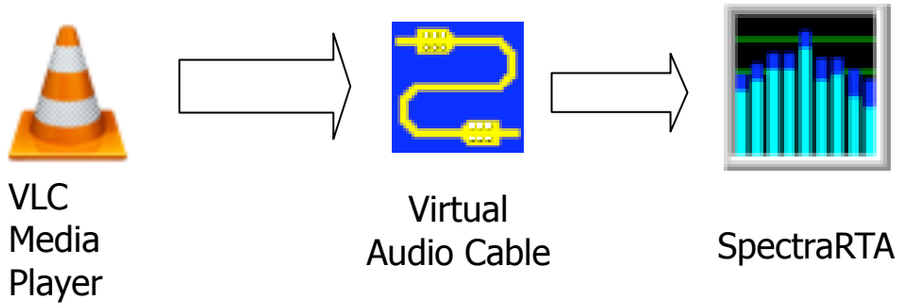
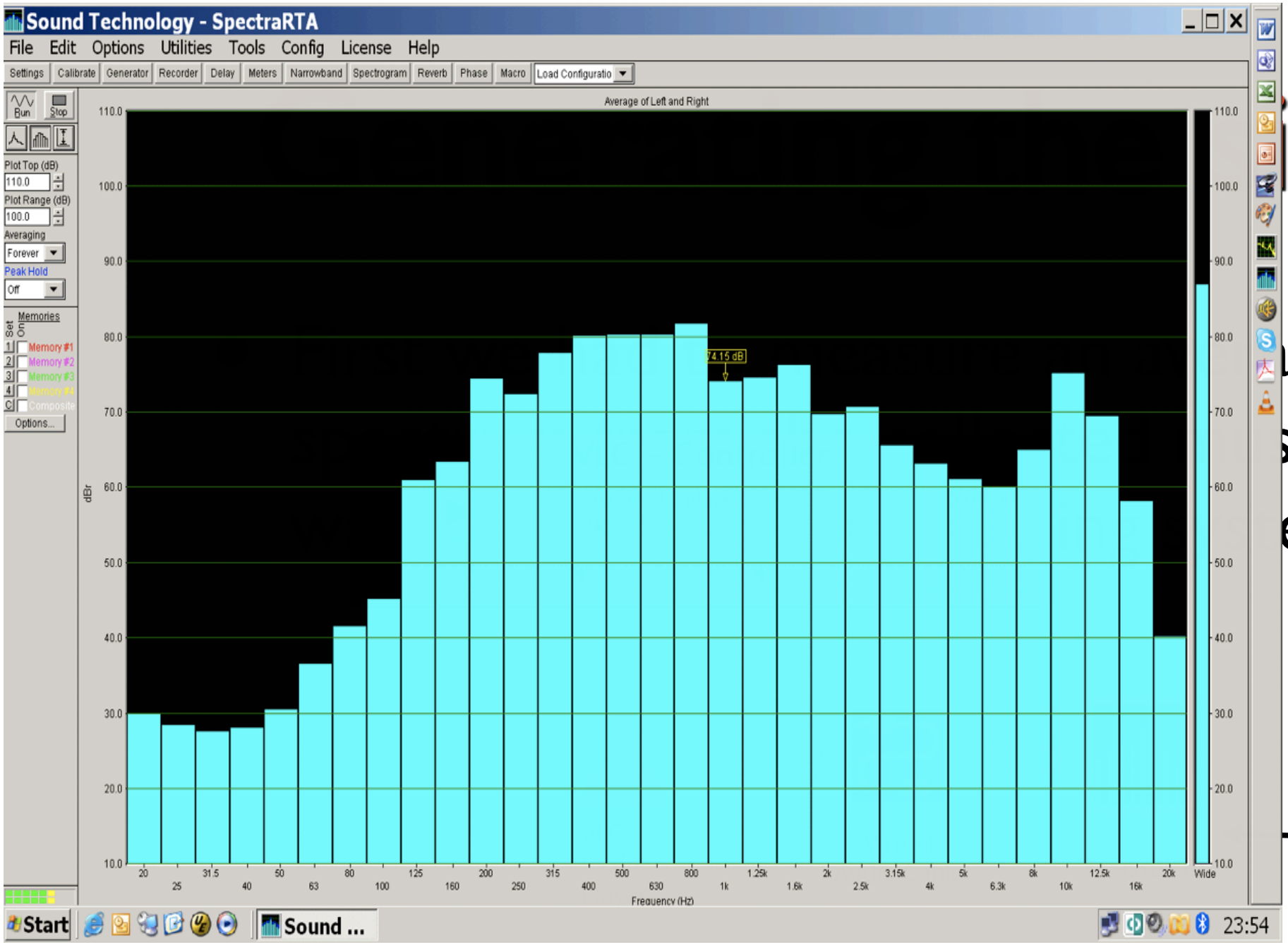


Measures 1/3 of octave spectrum



ignal

age

sic, which

em:

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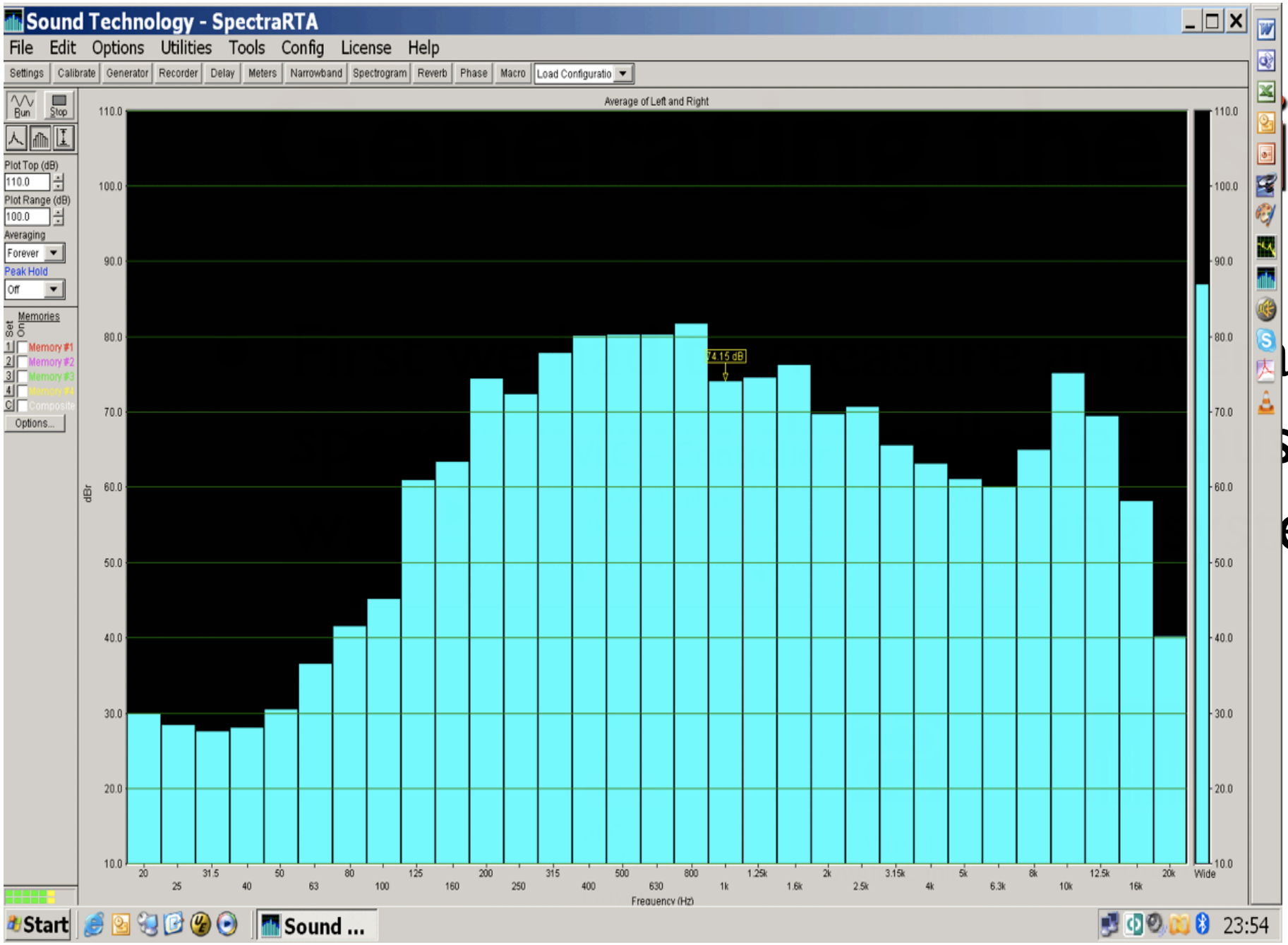

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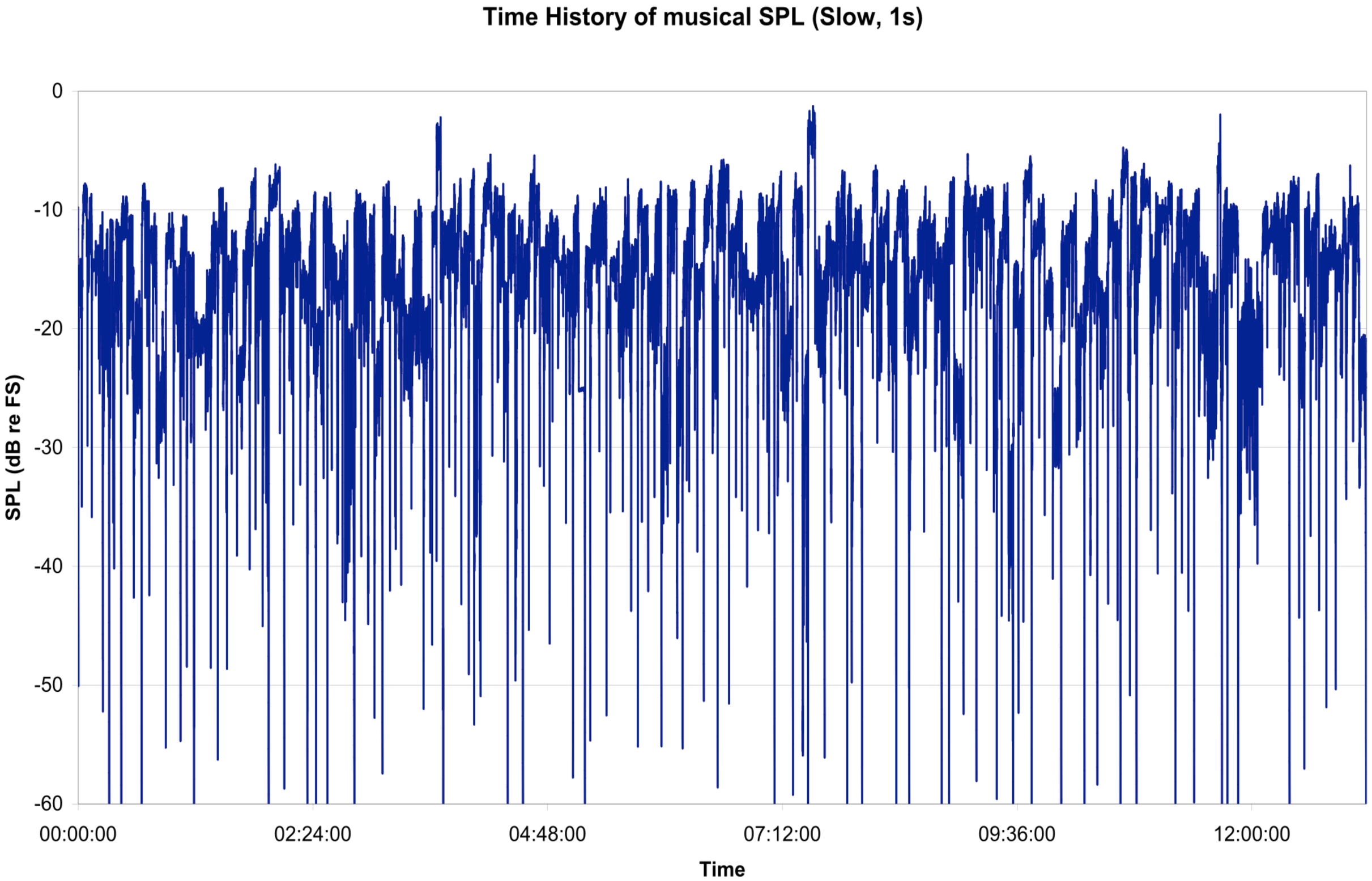
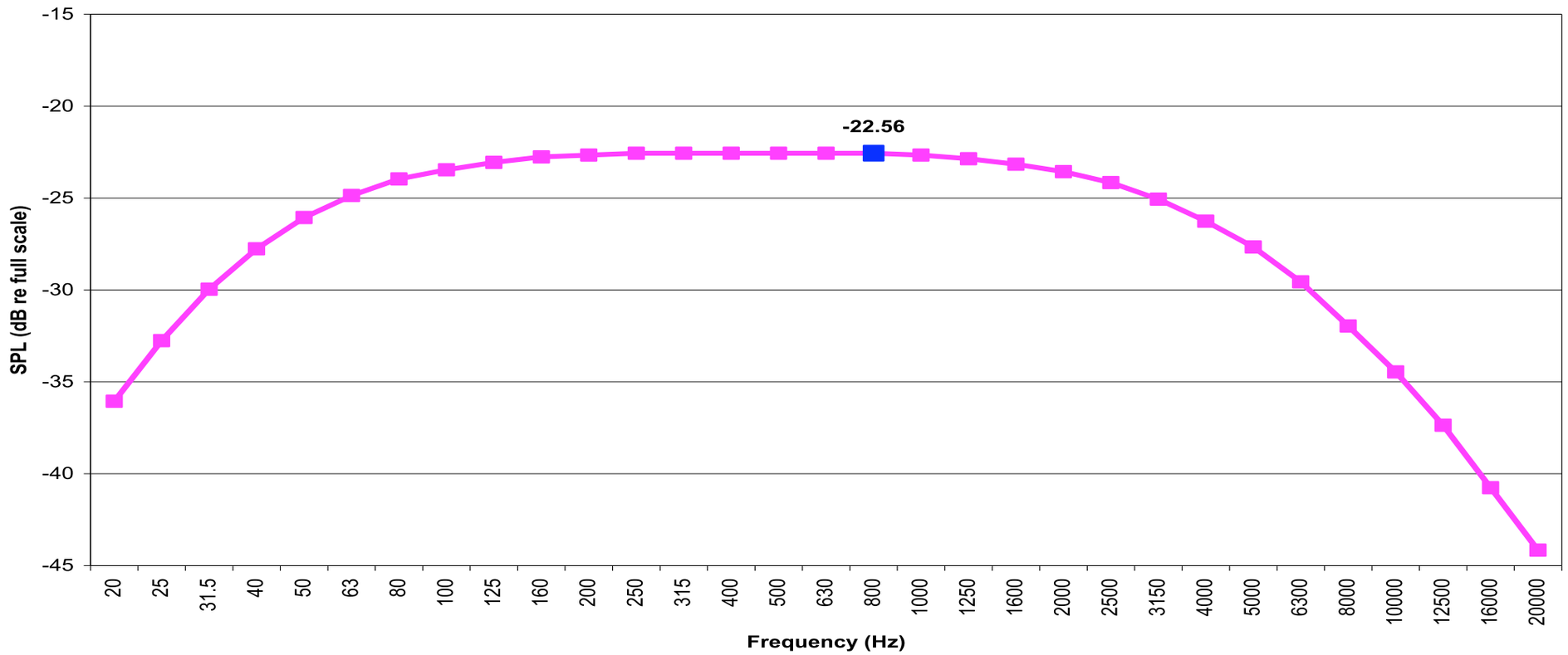

Time History of musical SPL (Slow, 1s)
SPL (dB re FS)
0
-10
-20
-30
-40
-50
-60
00:00:00
02:24:00
04:48:00
07:12:00
09:36:00
12:00:00
Time

Generating the signal

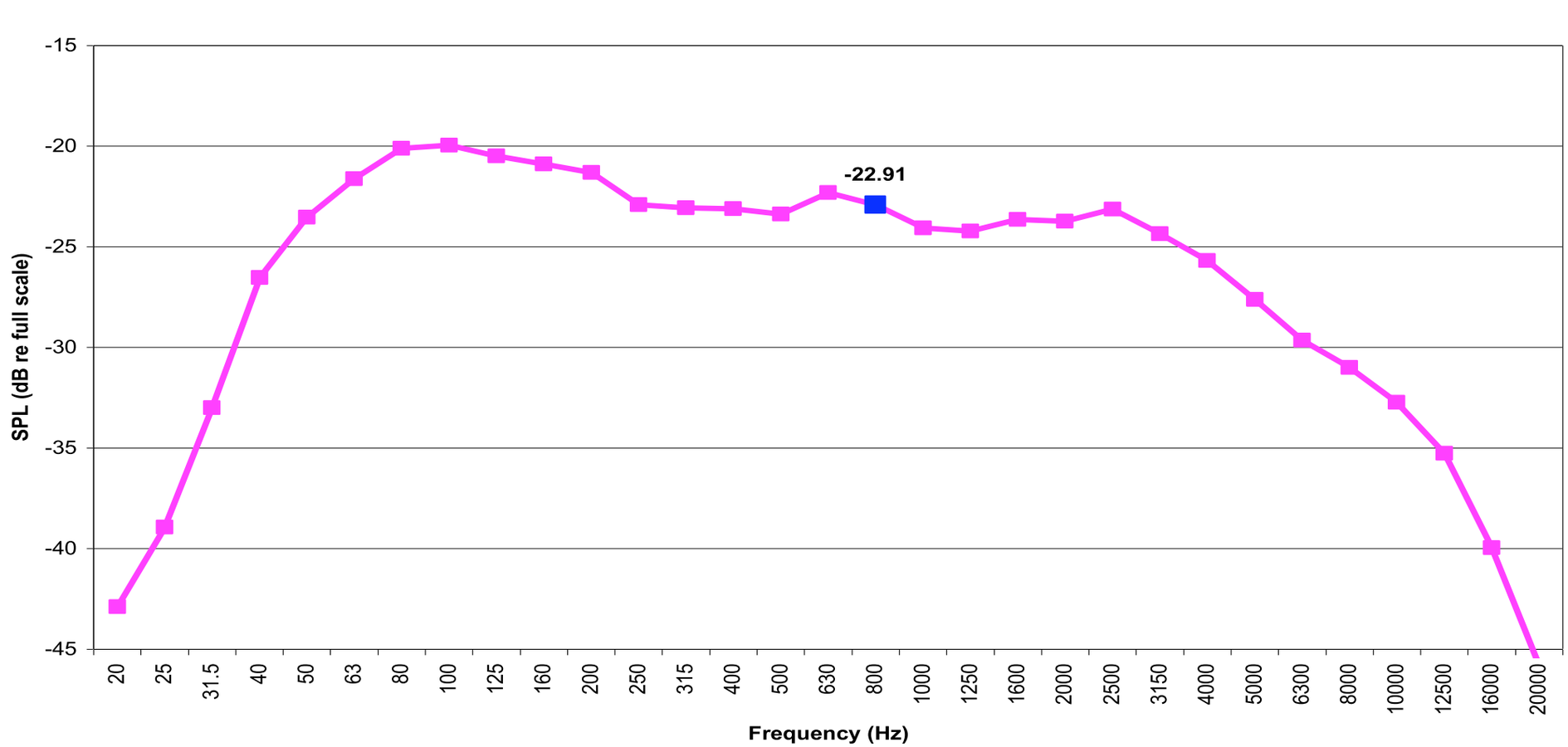
- We then proceeded to generate the signal using the same method employed for the IEC one

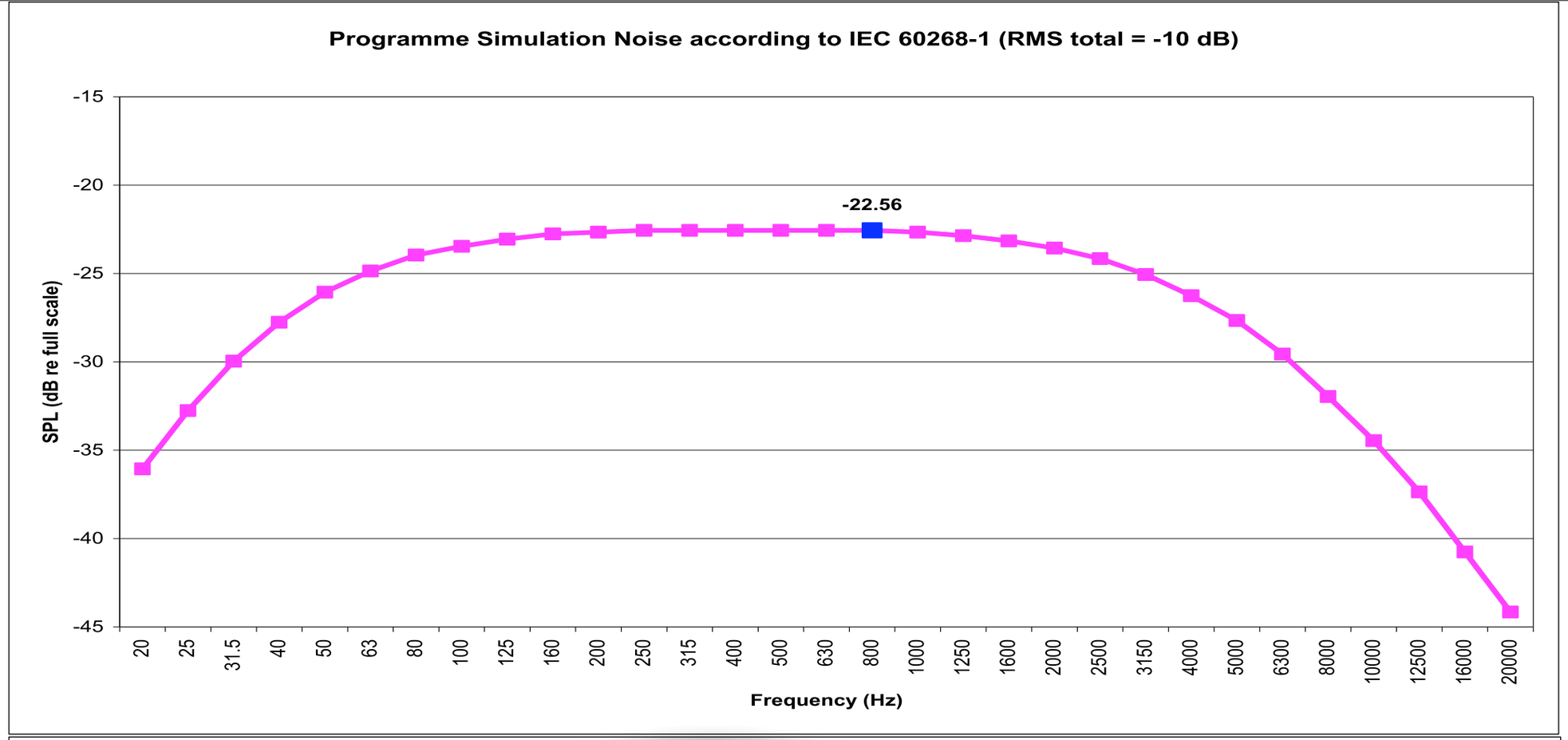
Signal Comparison

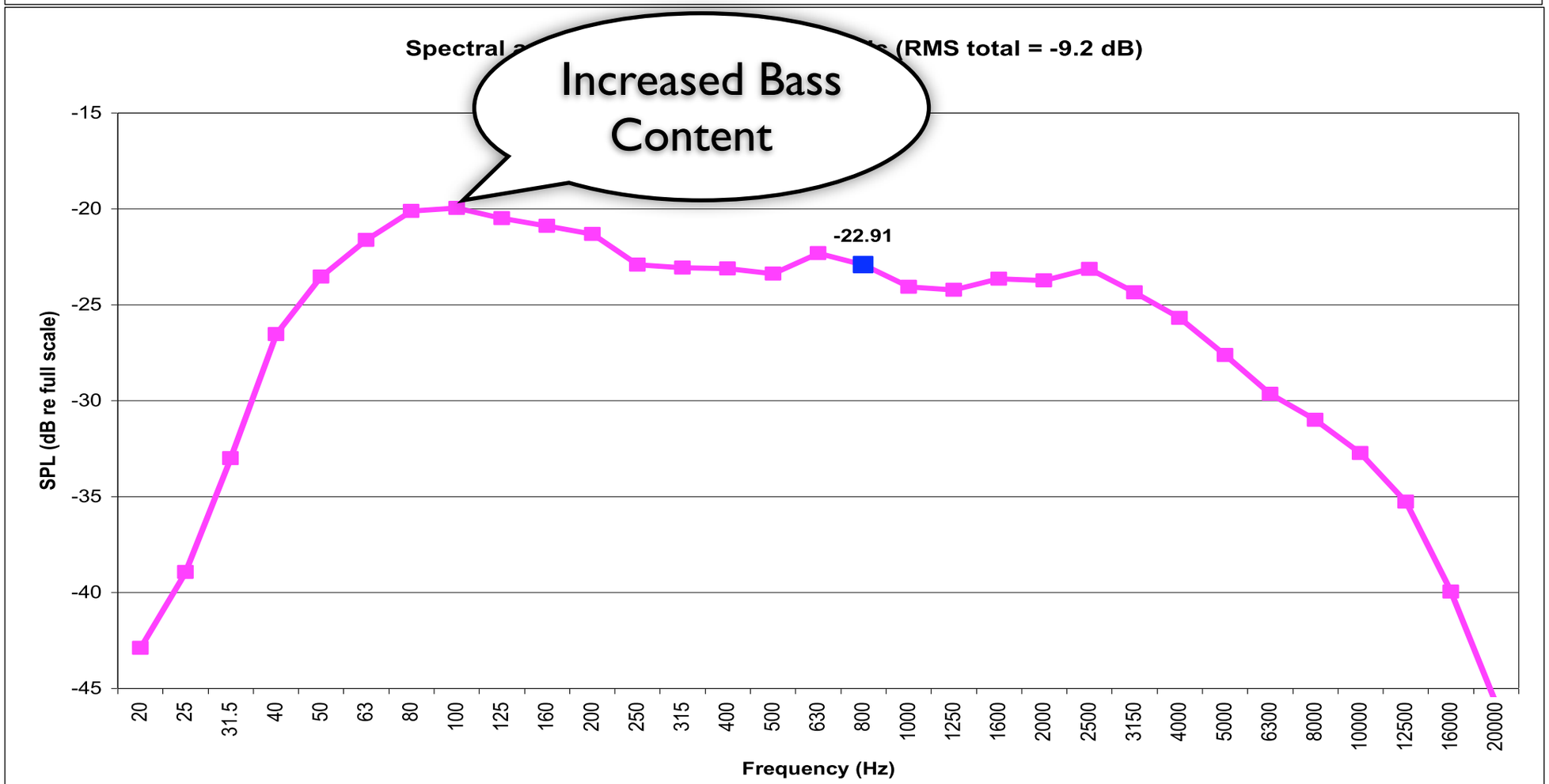
Programme Simulation Noise according to IEC 60268-1 (RMS total = -10 dB)



Spectral analysis of 16h of digital music (RMS total = -9.2 dB)




Programme Simulation Noise according to IEC 60268-1 (RMS total = -10 dB)
-22.56
SPL (dB re full scale)
-15
-20
-25
-30
-35
-40
-45
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
Frequency (Hz)


(RMS total = -9.2 dB)
Increased Bass Content
-22.91
SPL (dB re full scale)
-15
-20
-25
-30
-35
-40
-45
20
25
31.5
40
50
63
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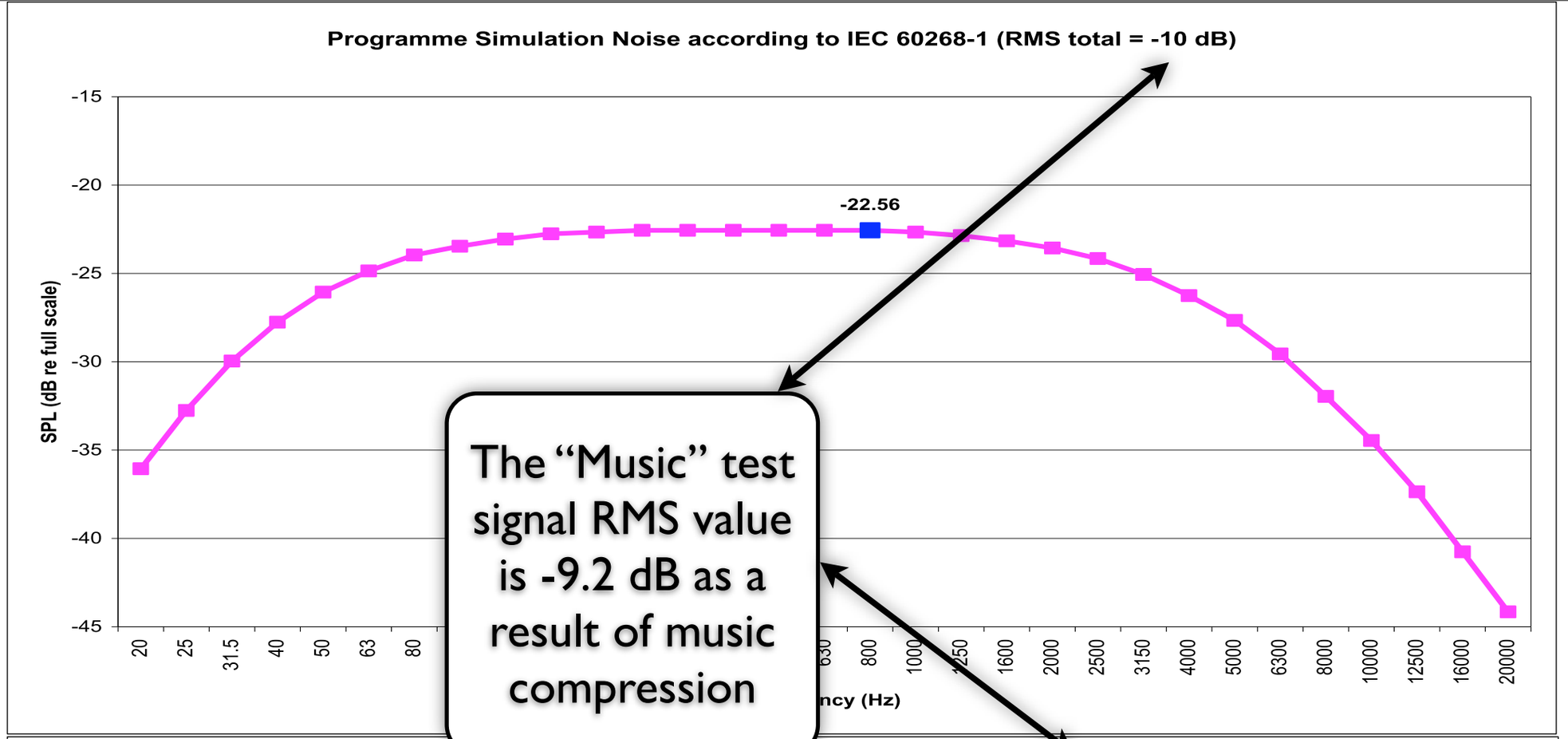
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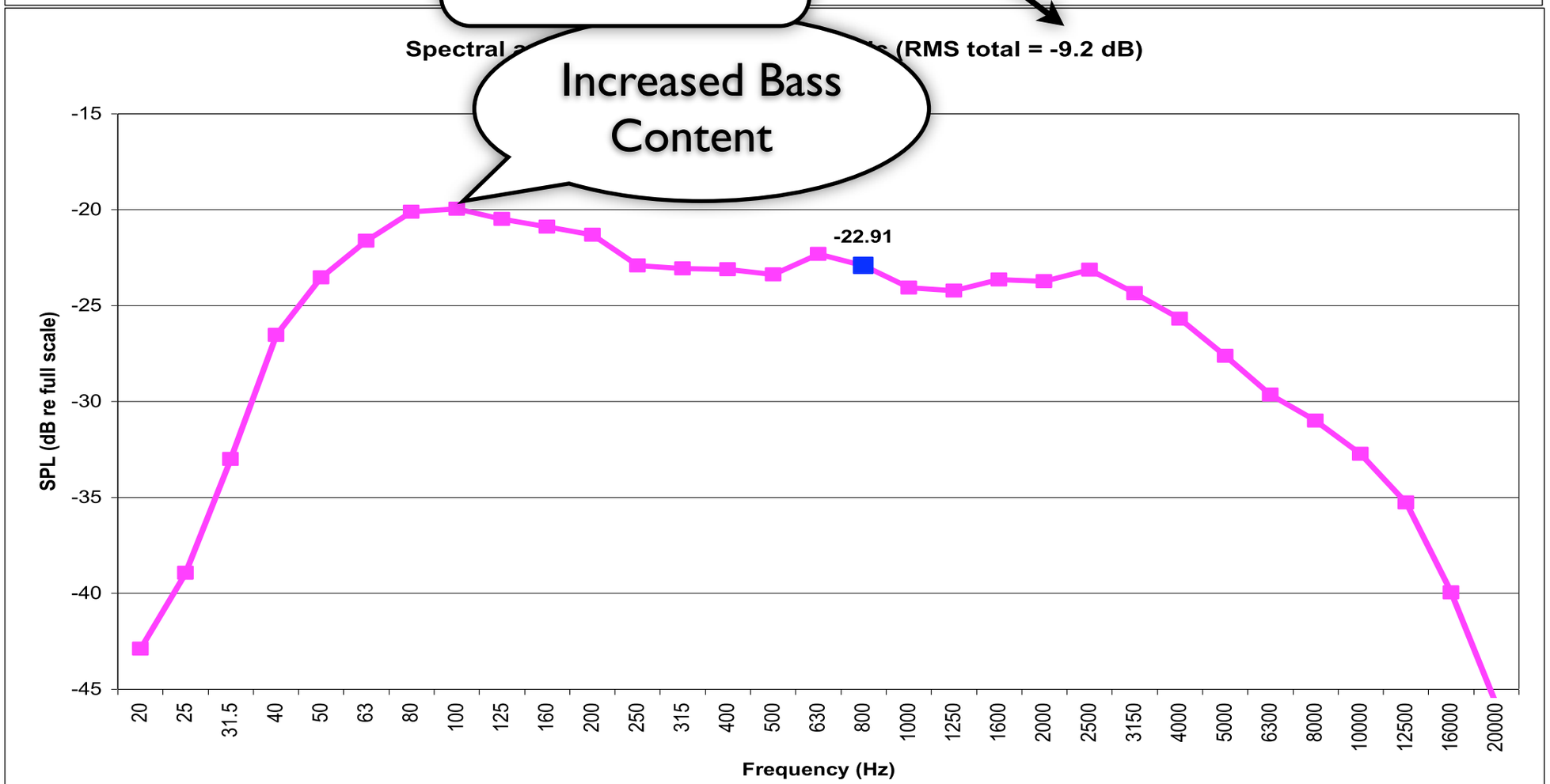
The "Music" test signal RMS value is -9.2 dB as a result of music compression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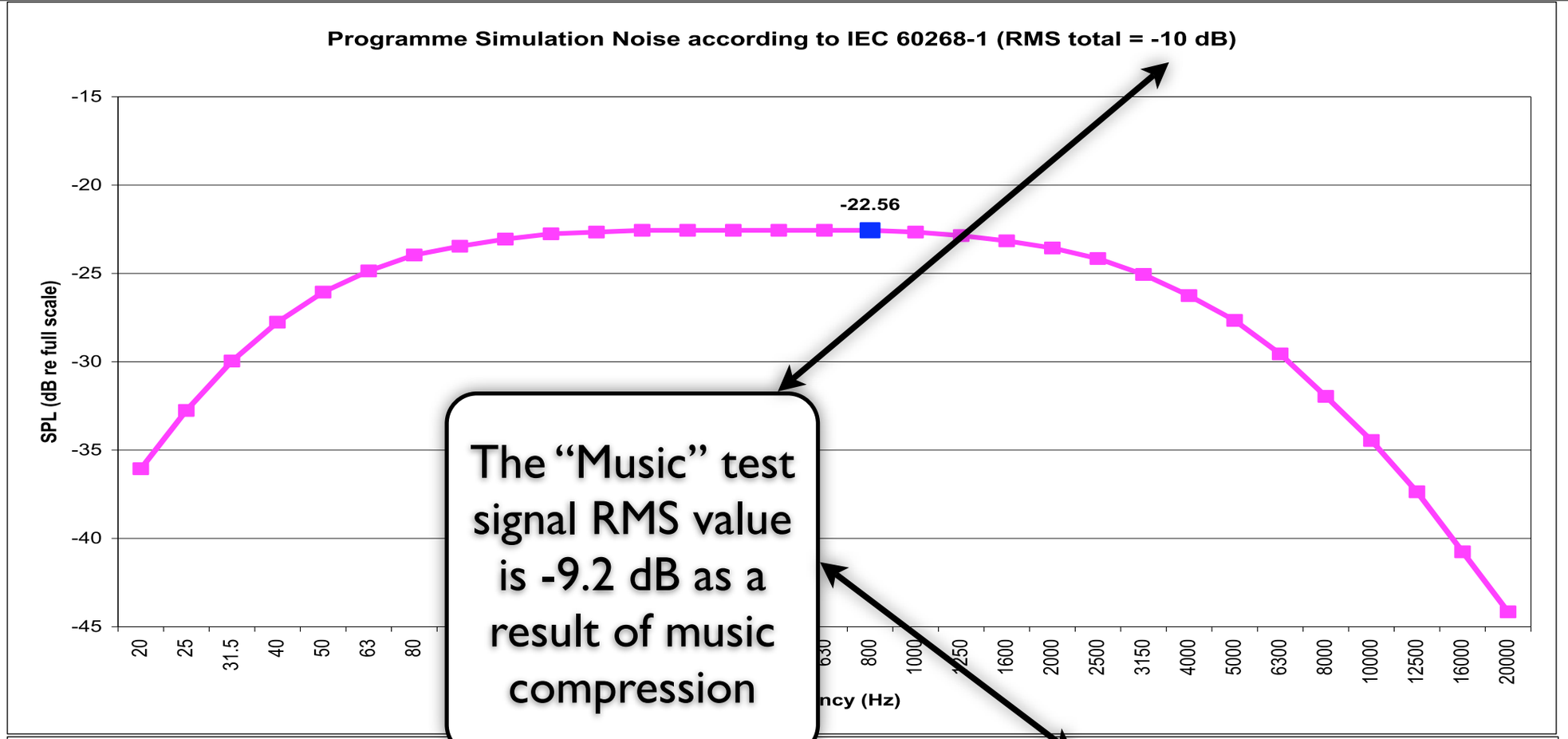
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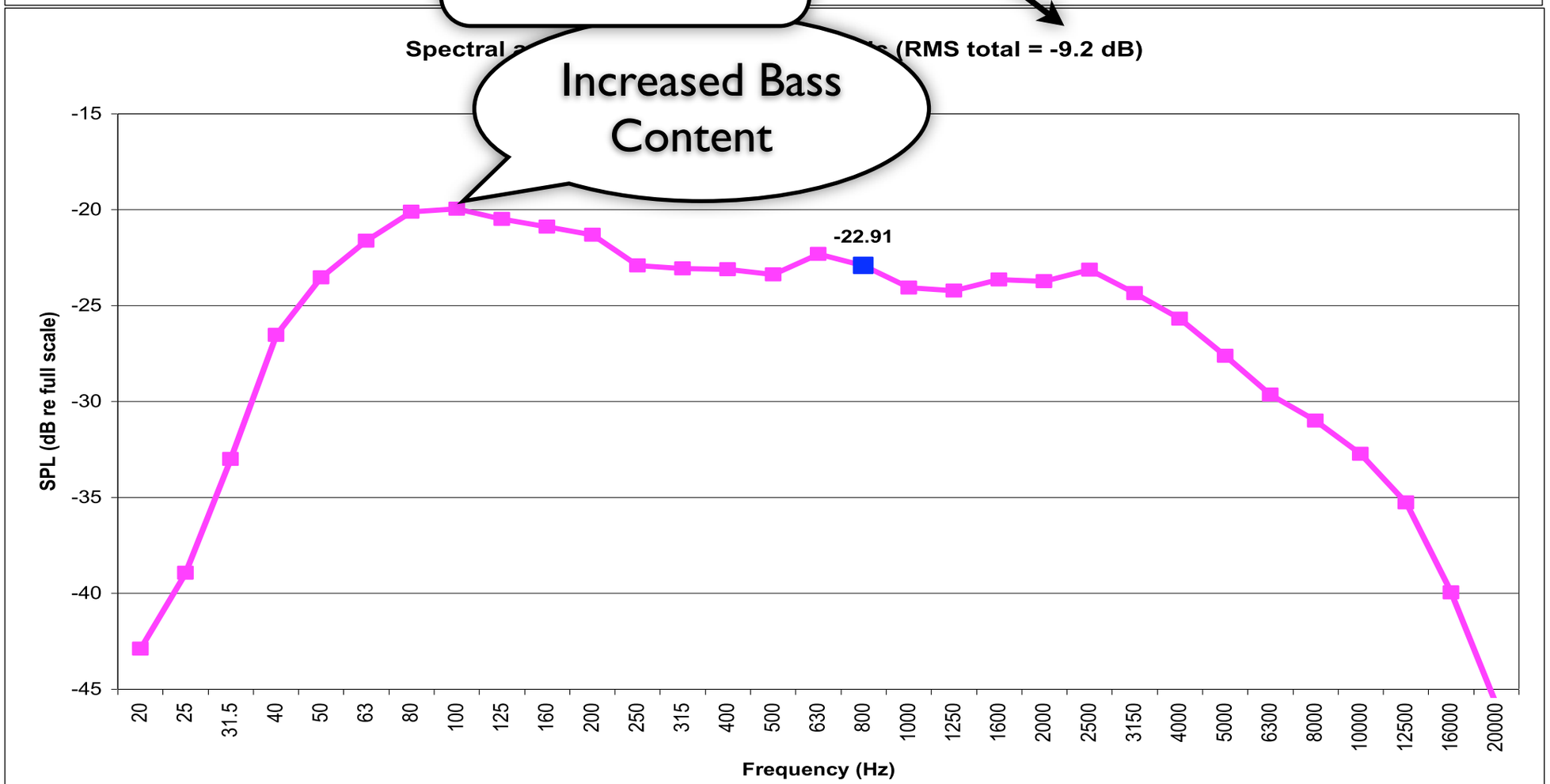
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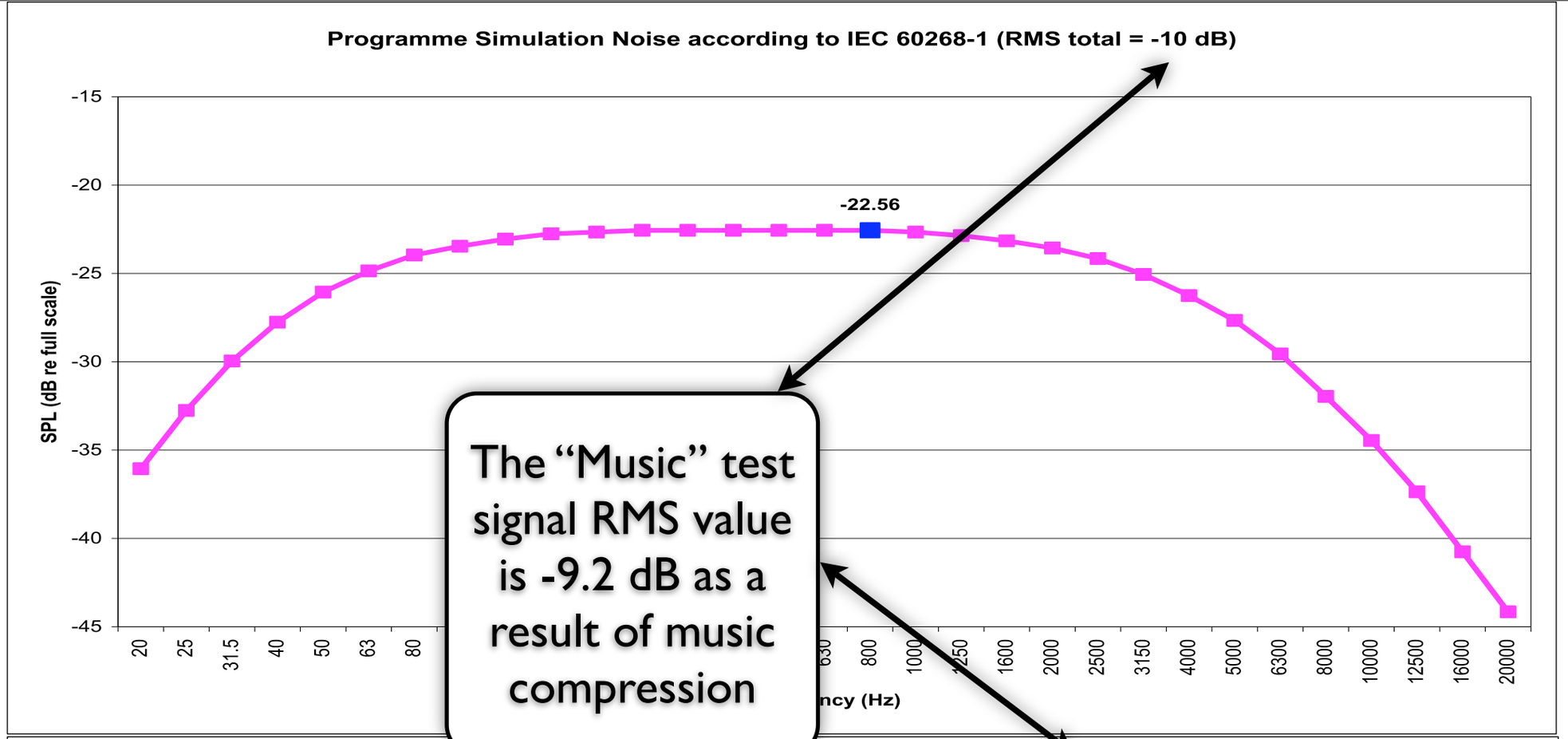
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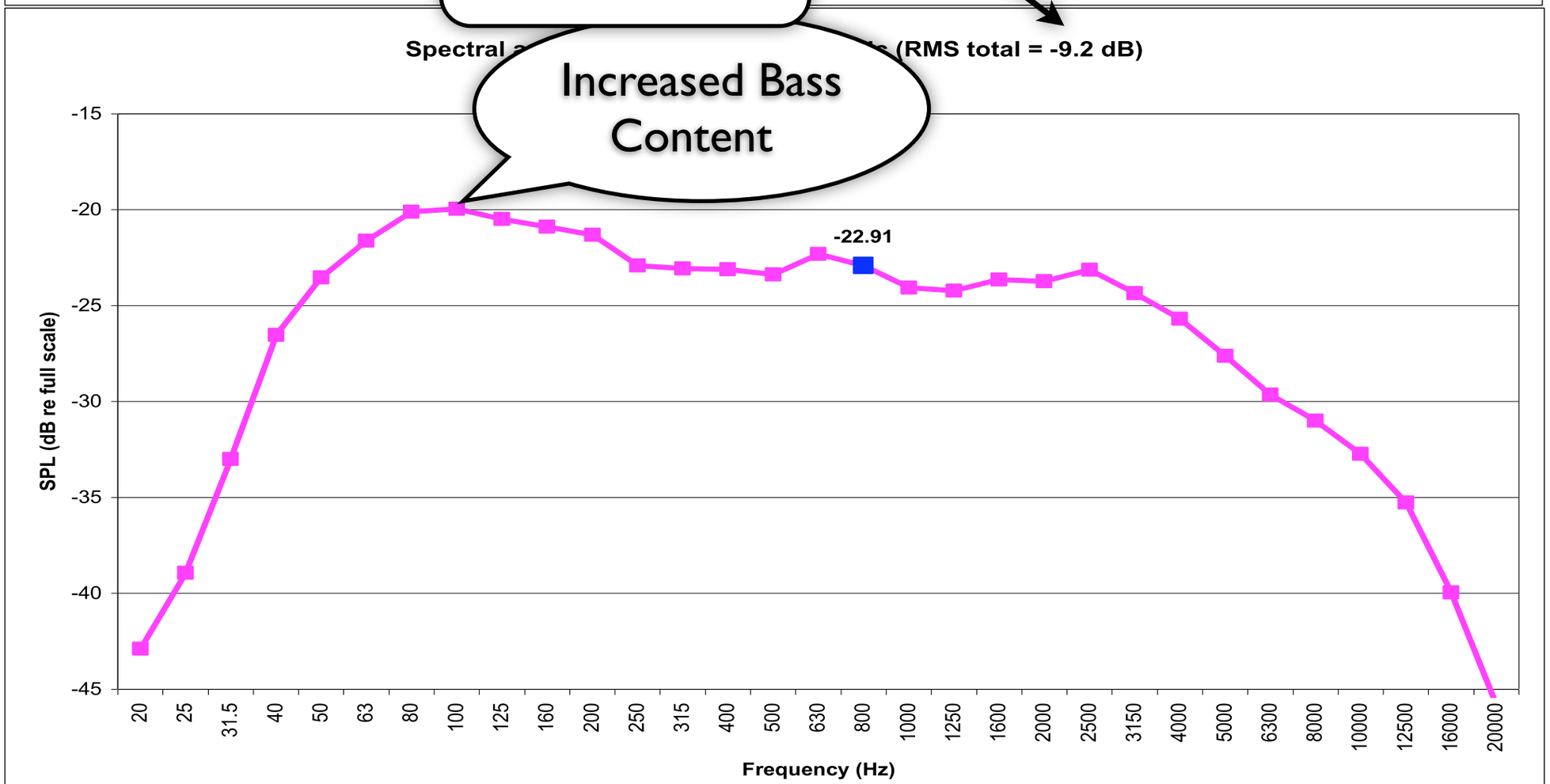
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Frequency (Hz)

File formats employed

- In order to perform the measurements the test signals were put on the digital audio players using the best codec available for each device (uncompressed wav when available). The formats employed are the following:

- Uncompressed WAV (44100 Hz, 16 bits, stereo)
- WMA Lossless
- WMA 192 kbps
- WMA 128 kbps
- MP3Pro 144 kbps
- MP3 192 kbps
- MP3 128 kbps
- Apple Lossless
- AAC 192 kbps
- AAC 128 kbps

As the difference between the same recording in different formats is very subtle, and does not usually require that the user adjusts the playback gain, we discarded the fact that different file formats were employed on different devices.

Equipment and calibration


Hearing with HI
moderate severe
Hearing without HI
Normal Loss

Ambassador dummy head

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- This dummy head is compliant with IEC 60959, and is specifically manufactured for testing "internal" hearing aids

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- The microphones have been calibrated, removing the pinna, and inserting over the capsule a Bruel & Kjaer type 4100 reference sound source, which provides a pure tone at the frequency of 1 kHz and with an RMS sound pressure level of 94 dB (1 Pa).

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- The calibration signal was employed for setting the calibration of the SpectraRTA program, as shown here:

Ambassador dummy head

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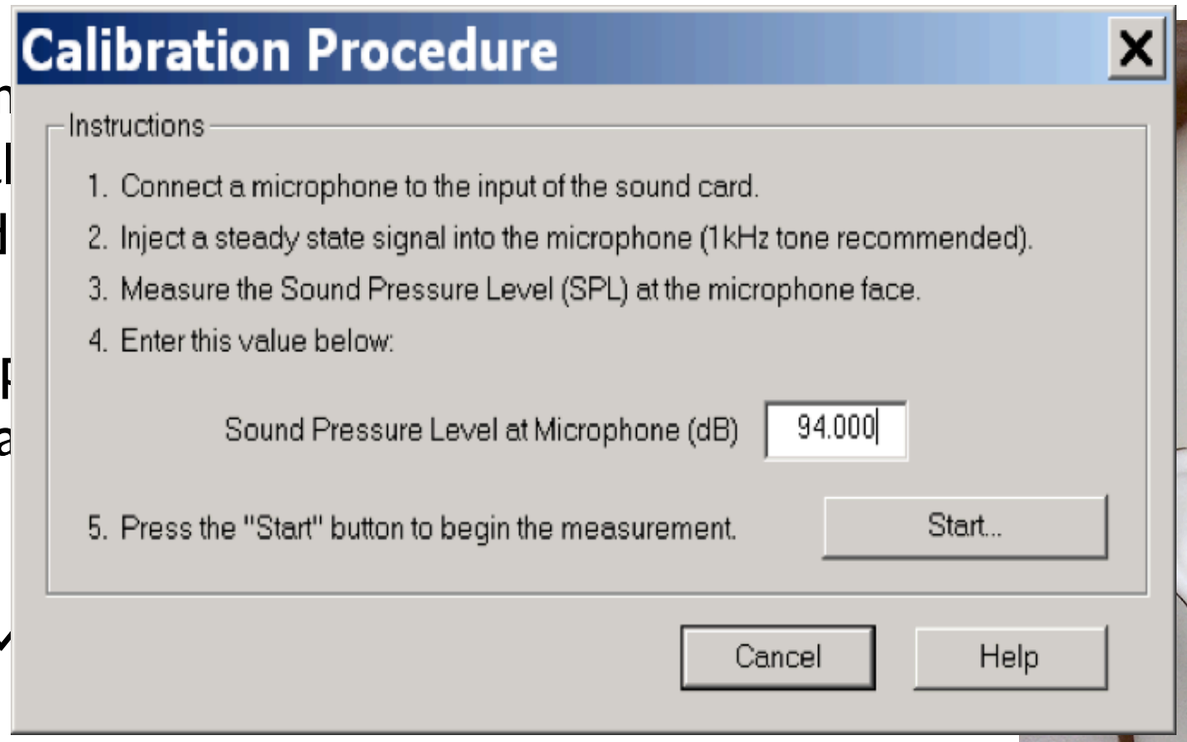
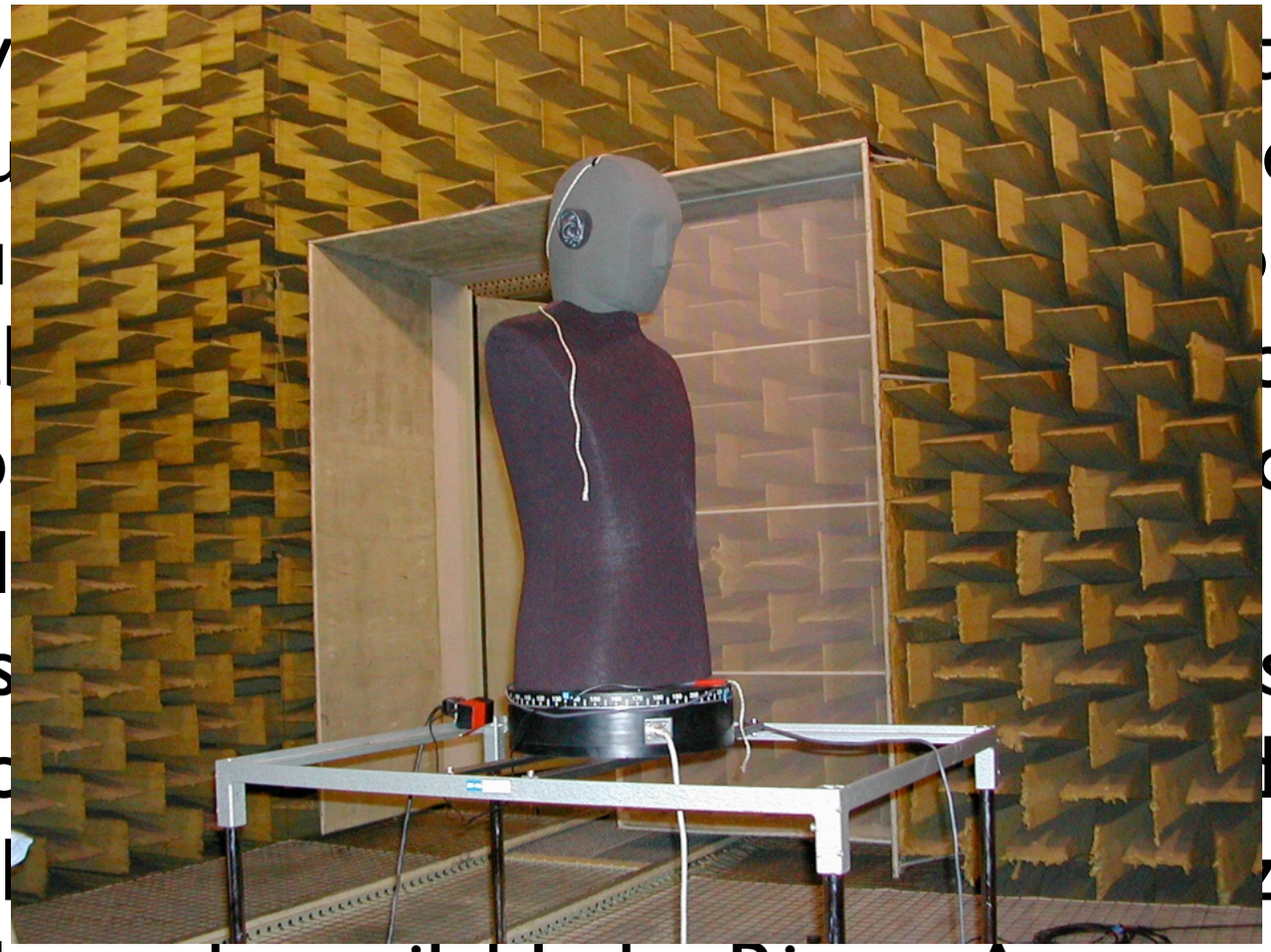


Ambassador dummy head

Ambassador dummy head

- However, it is also necessary to correct for the frequency response of this specific Head and Torso Simulator. The manufacturer does not provide a suitable free-field frequency response for the Ambassador dummy head. So it was necessary to employ the results of anechoic impulse response measurements which had been previously performed on this specific dummy head at the anechoic chamber of Winterthur (Switzerland), kindly made available by Rieter Automotive.

Ambassador dummy head

- How  t for the frequ d and Torso Simu rovide a suita or the Amb cessary to empl response meas sly perfo l at the anec zerland), kindly made available by Rieter Automotive.

Ambassador dummy head

- Ho… …r the
fre… …and Torso
Sim… …vide a
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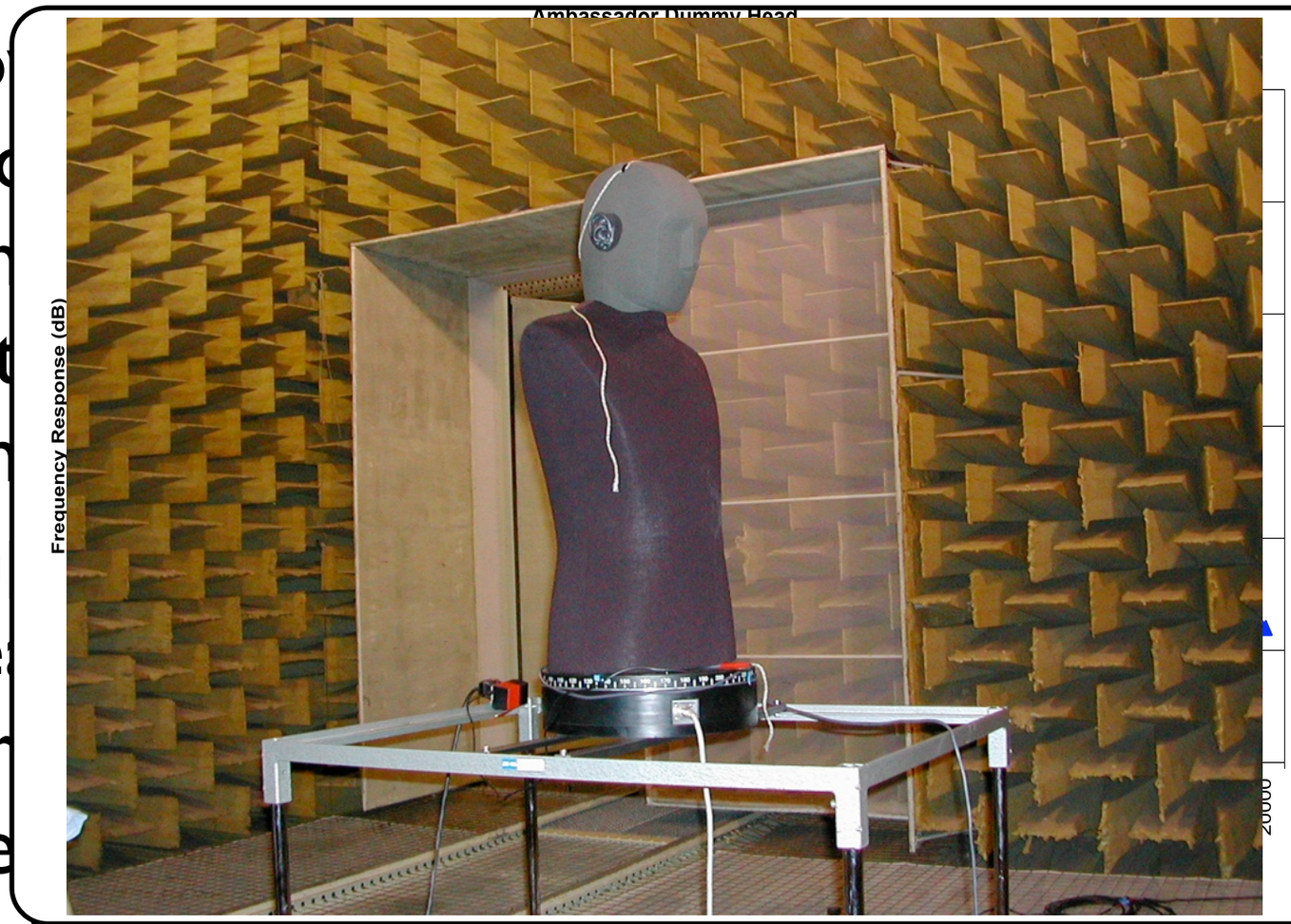
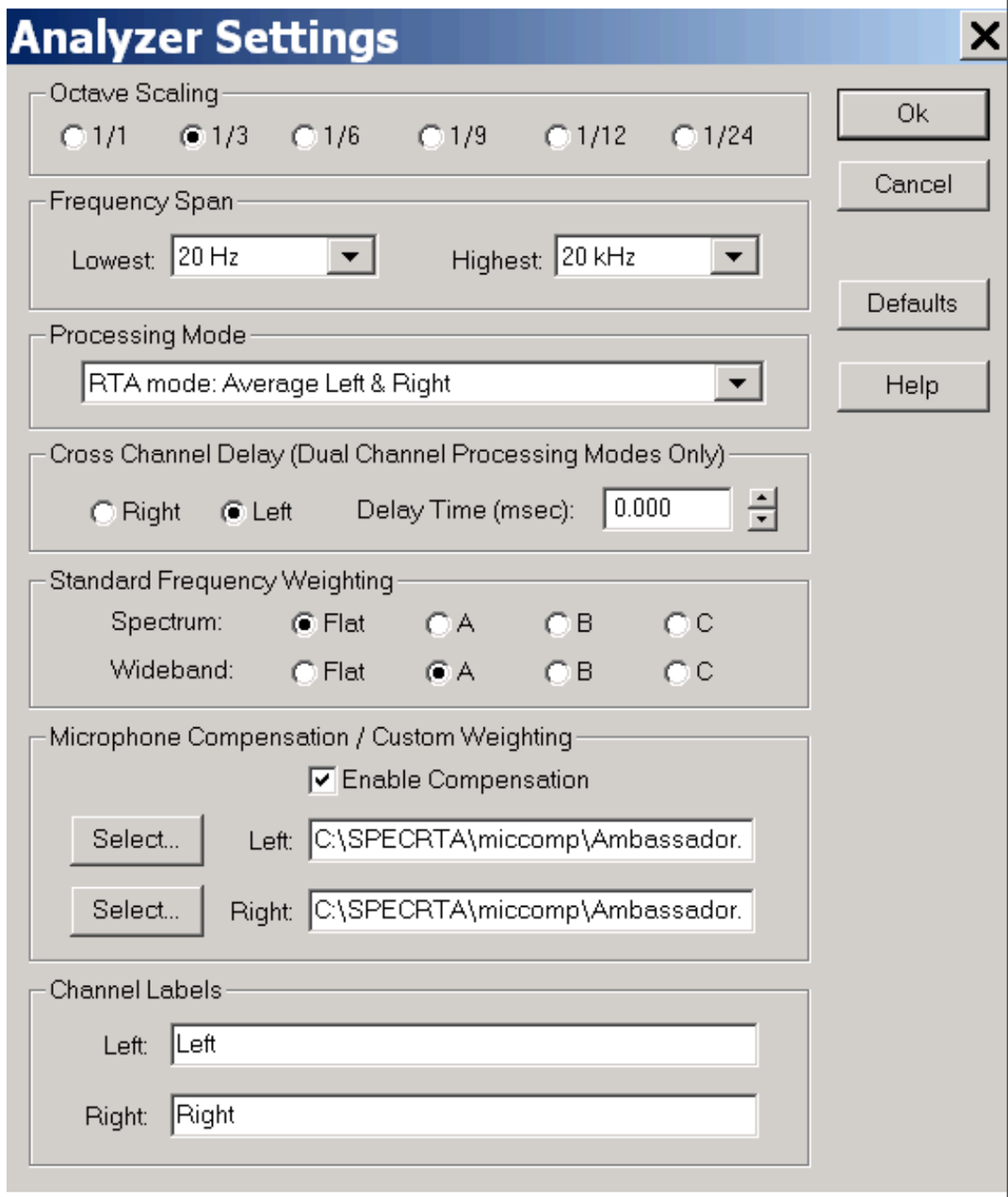


Frequency Response Correction

- SpectraRTA already provides the capability of correcting for the frequency response of the microphones employed, so the compensation of the frequency response of the Ambassador dummy head did not require any effort.



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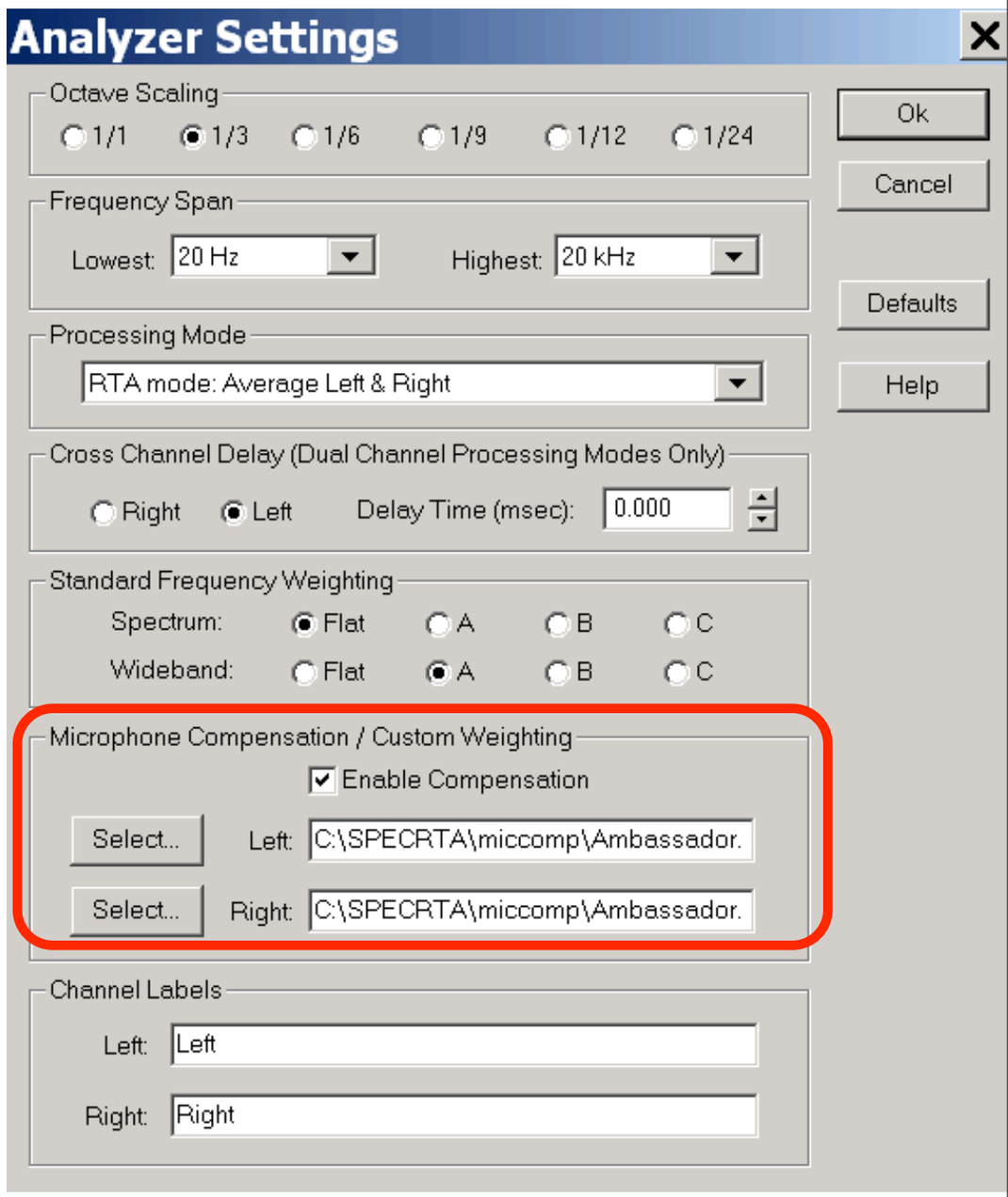
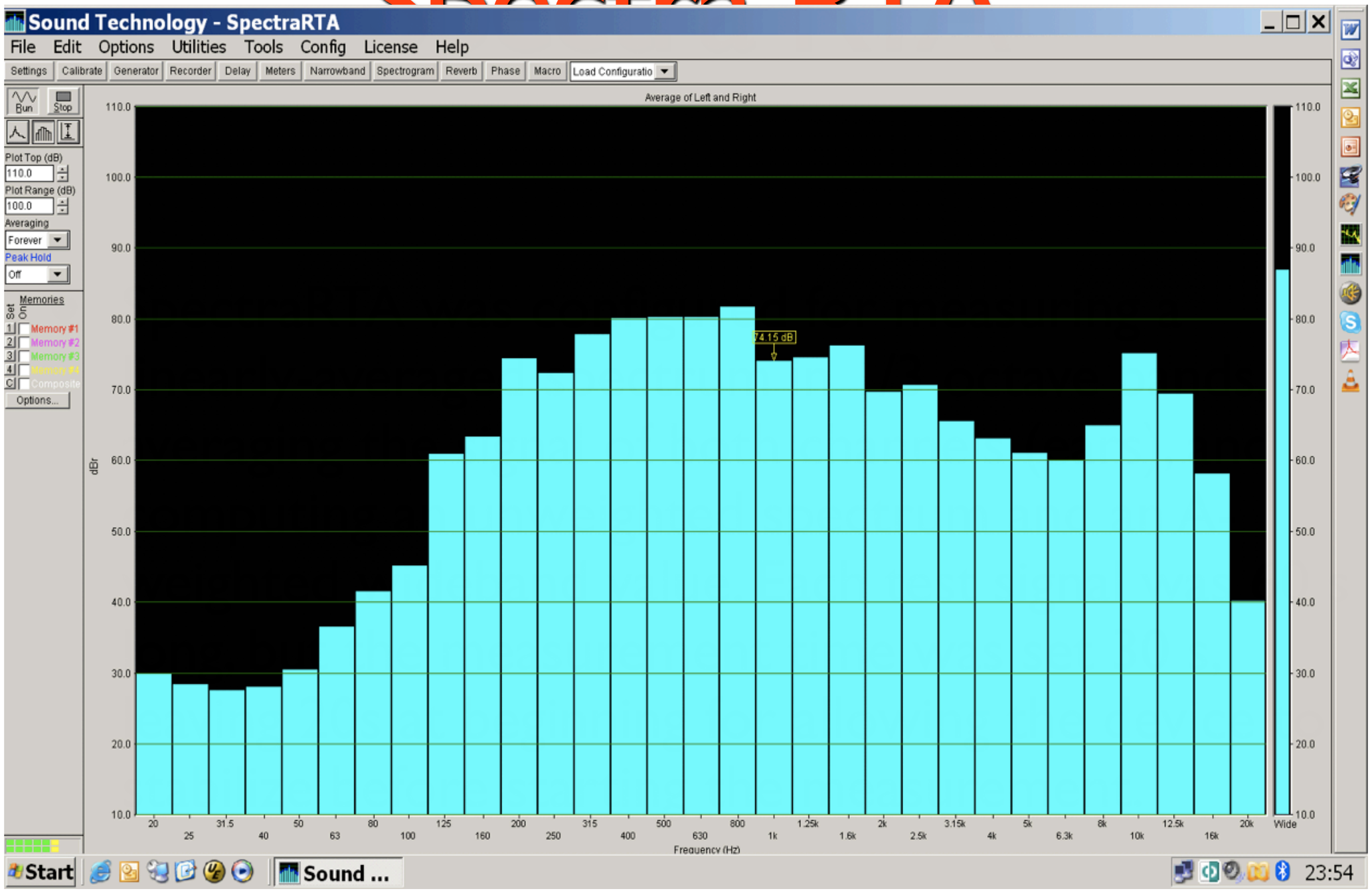


Spectra RTA

Spectra RTA

- SpectraRTA was configured for measuring a linearly-averaged spectrum in 1/3 octave bands, averaging the signal of both channels (ears), and computing an unweighted spectrum and an A-weighted wideband value. Each test signal was 60 s long, but the measurement time was set 30 s, leaving 20s at beginning for allowing the device to stabilize before starting the measurement.

Spectra RTA


Sound Technology - SpectraRTA
File Edit Options Utilities Tools Config License Help
Settings Calibrate Generator Recorder Delay Meters Narrowband Spectrogram Reverb Phase Macro Load Configuratio
Run Stop
Plot Top (dB)
110.0
Plot Range (dB)
100.0
Averaging
Forever
Peak Hold
Off
Memories
Set On
1 Memory #1
2 Memory #2
3 Memory #3
4 Memory #4
C Composite
Options...
Average of Left and Right
74.15 dB
dBr
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
20 25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1k 1.25k 1.6k 2k 2.5k 3.15k 4k 5k 6.3k 8k 10k 12.5k 16k 20k
Frequency (Hz)
Wide
Start
Sound ...
23:54

Measurement procedure

Measurement procedure

- Each device was measured 5 times, dismounting and remounting the headphones each time, as recommended by standard EN 50332, in order to reduce the mounting error. The results were then averaged.

Measurement procedure

- Each device was measured 5 times, dismounting and remounting the headphones each time, as recommended by standard EN 50332, in order to reduce the mounting error. The results were then averaged.
- For ensuring a better correlation between the results and in order to minimize the measurement time, we used the same headphone position with both test signals (IEC and MUSIC). The headphone was inserted, then the two signals were measured and then the headphones were removed and reinserted.

Measurement procedure

- Each device was measured 5 times, dismounting and remounting the headphones each time, as recommended by standard EN 50332, in order to reduce the mounting error. The results were then averaged.

- For ensuring a better correlation between the results and in order to minimize the measurement time, we used the same headphone position with both test signals (IEC and MUSIC). The headphone was inserted, then the two signals were measured and then the headphones were removed and reinserted.

- The volume control of the player was left untouched since the last usage from the owner of the device. These results are thence not significant for discriminating "dangerous" devices from "safe" devices.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Results

SPL Measurements

- For each device under test it was possible to obtain two values of the “exposure sound pressure level”: the first based on the IEC programme test signal, the second on the MUSIC test signal. The following table shows the results, in terms of average SPL +/ the standard deviation.

Player	IEC	Std.Dev.	MUSIC	Std.Dev.
Napa	74.2	3.1	74.2	2.7
Ipod_jacopo	96.8	2.7	94.7	1.8
Ipod_Bonach	96.2	3.2	96.4	3.7
Zen_Furla	95.7	6.0	95.1	5.7
Ipod_Ganda	91.0	2.6	90.9	2.6
Ipod_Pater	103.9	1.4	103.4	0.8
Packard_Giovati	60.2	4.3	62.0	3.2
Usb_Schianchi	78.4	1.3	77.8	2.6
Archos_Gio	85.2	1.2	85.7	1.2
Ipod_Marianna	87.4	5.9	88.0	6.0
mp4_Tommaso	76.0	3.2	75.2	2.9
Ipod_Gabriele	81.4	3.6	80.5	4.1
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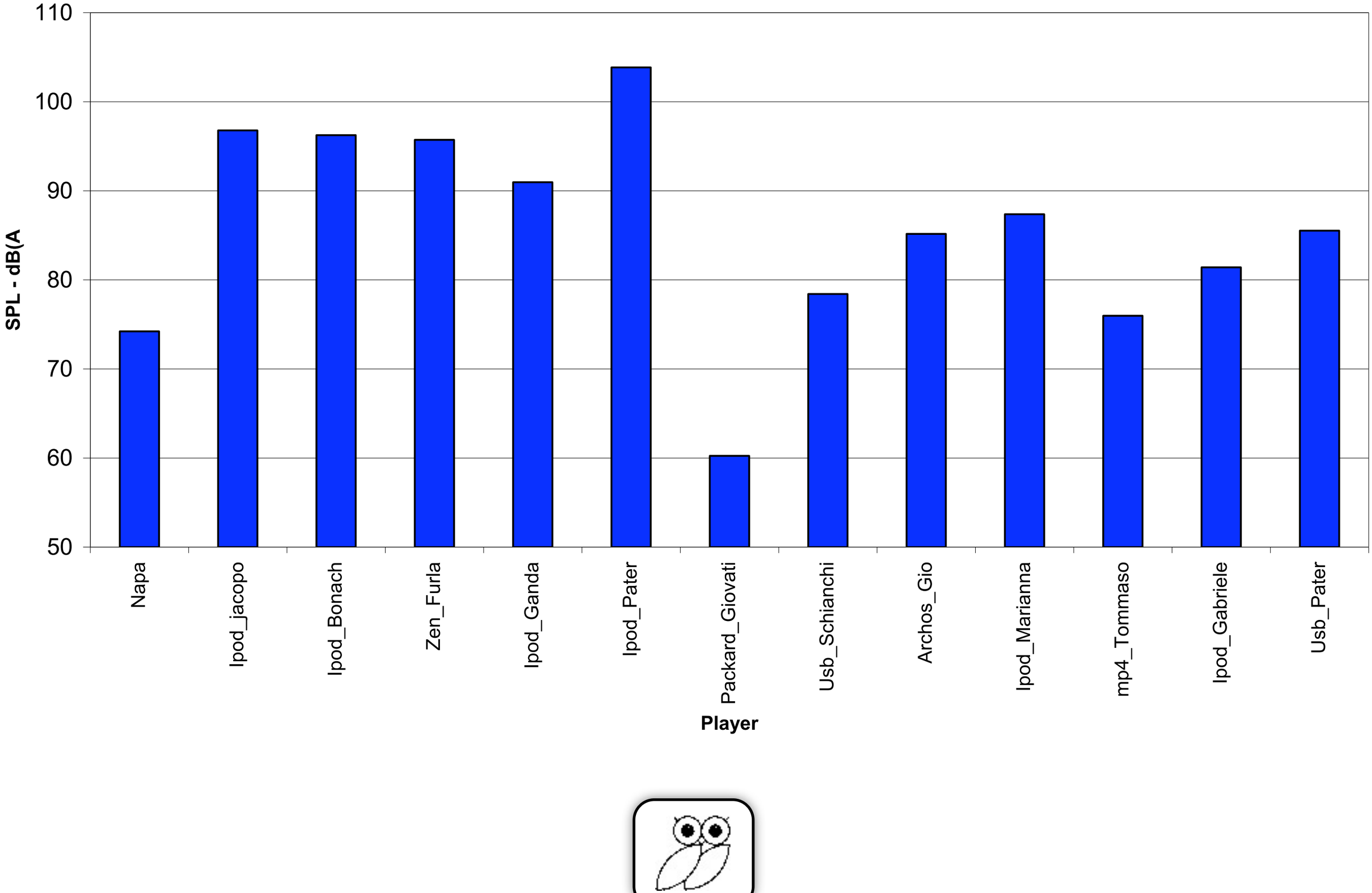
Sound Pressure Level with IEC signal



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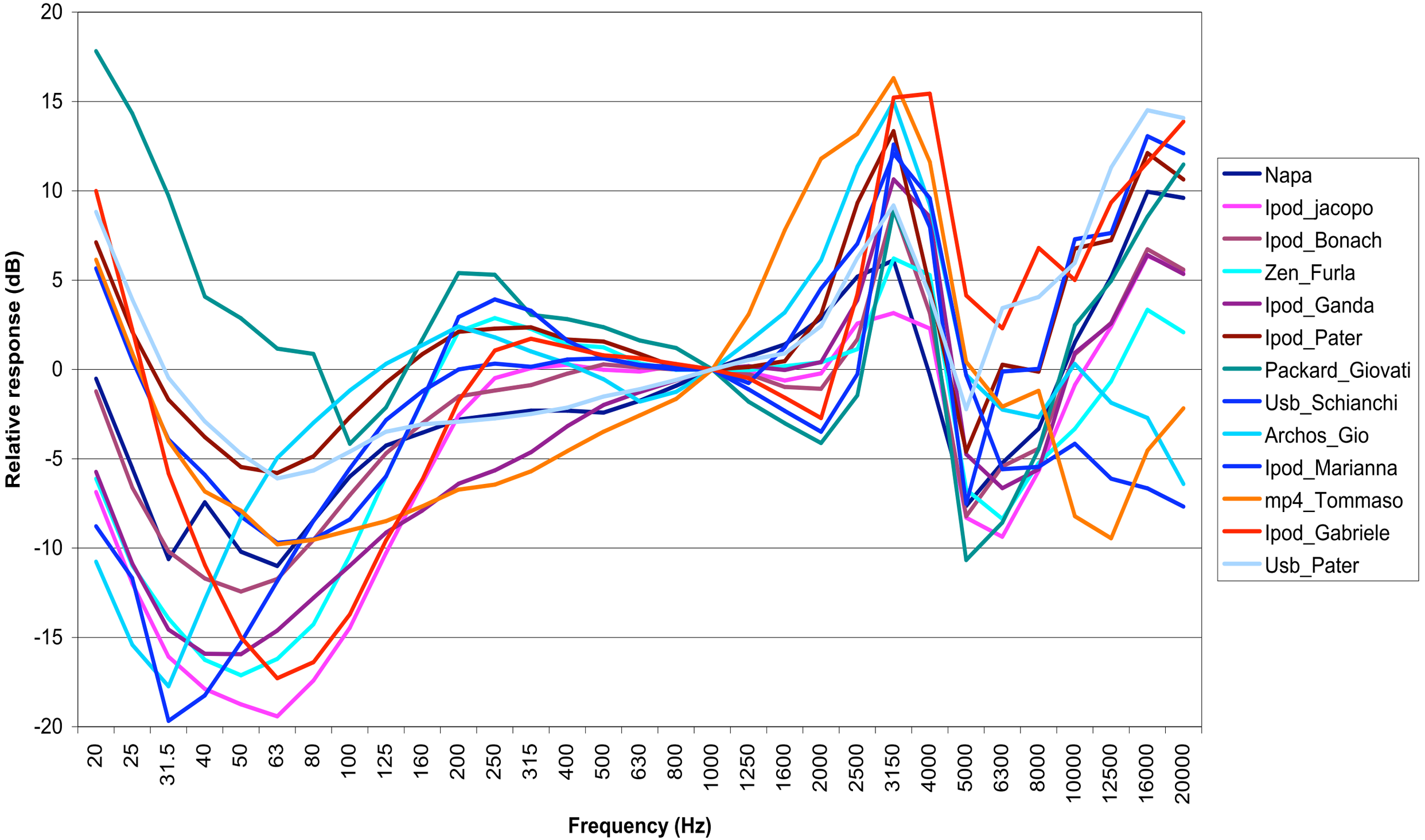
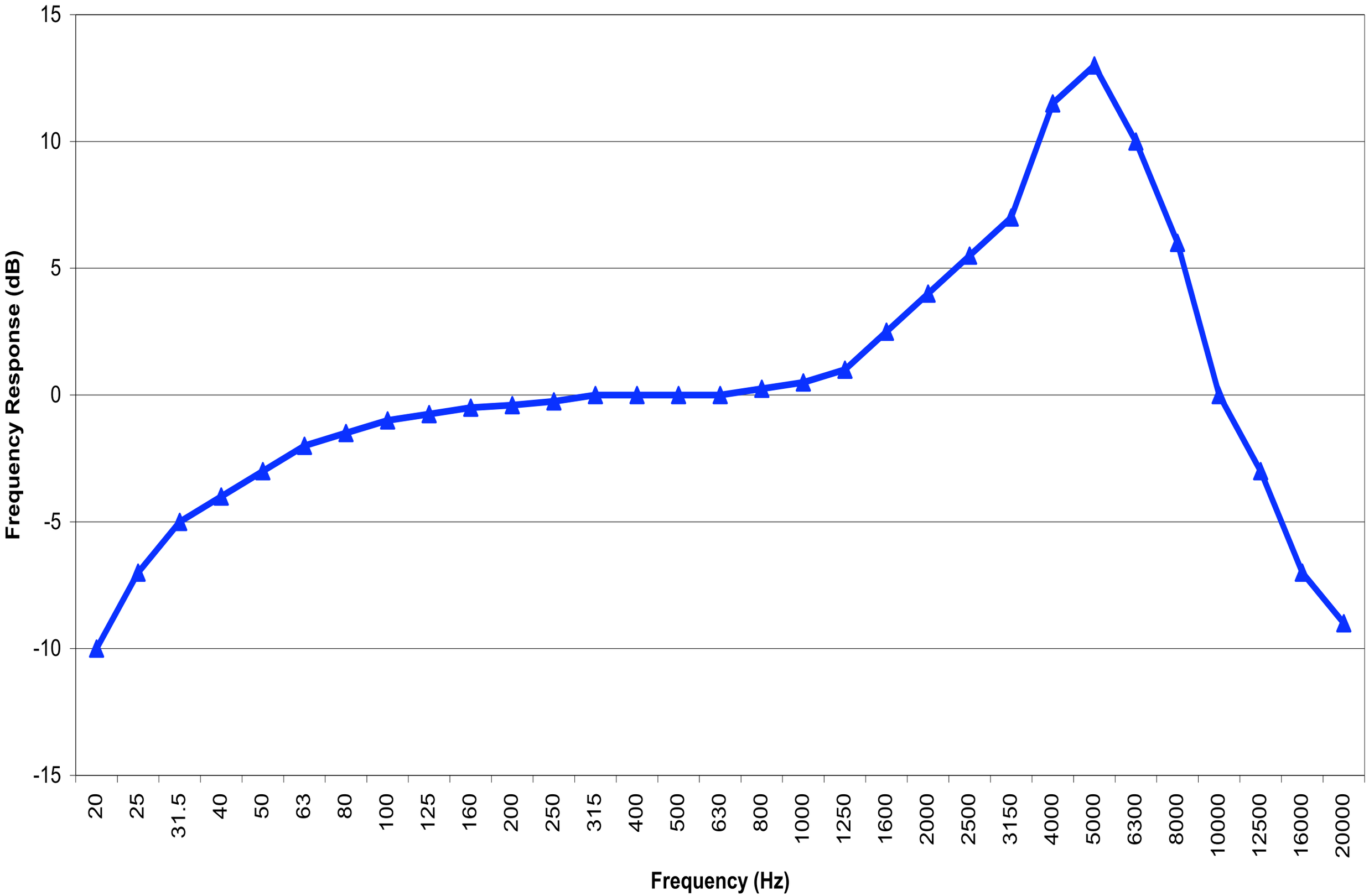
- Looking at the free-field frequency response of the Ambassador dummy head, the peak in the frequency response was instead at 5 kHz, corresponding to the “dip” in the curves of the figure.

Frequency Responses



Ambassador Dummy Head



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Frequency Response

- It is wrong to employ the free-field frequency response for correcting the recorded signals, as the free-field response does not take into account the modification of the ear duct resonance occurring when an ear bud is inserted in the pinna.
- This can be seen as a severe inconsistency of the current EN 50332-1 standard.
- It could be more advisable to employ a diffuse-field response (which is usually smoother)

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- Whenever higher SPL values are present, the duration of the exposure should be reduced, in order of keeping the same daily "noise dose". An energetic equivalence principle is assumed, which means that the exposure should be reduced at 4h for an SPL of 83 dB(A), to 2h for an SPL of 86 dB(A), and so on.

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- For each of the devices under test, it was computed what is the maximum time allowed daily for employing it for listening to music, as shown in the following table:

Player	Time (hh:mm)
Napa	06:13
Ipod_jacopo	00:10
Ipod_Bonach	00:11
Zen_Furla	00:12
Ipod_Ganda	00:38
Ipod_Pater	00:01
Packard_Giovati	No Limit
Usb_Schianchi	11:30
Archos_Gio	02:26
Ipod_Marianna	01:27
mp4_Tommaso	20:11
Ipod_Gabriele	05:46
Usb_Pater	02:14

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